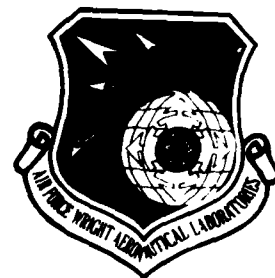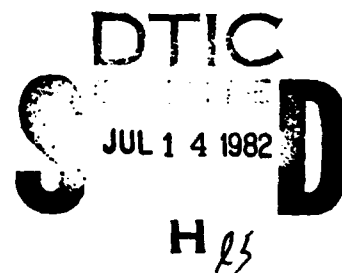AFWAL-TR-81-3079

HANDBOOK OF FORCE MANAGEMENT METHODS

A. P. Berens
University of Dayton Research Institute
Dayton, Ohio 45469-0001

D. S. Morcock, K. E. Brown, J.C. Davis, and R.L. Johnson
Lockheed-Georgia Company
Marietta, Georgia 30063

C. E. Larson and D. J. White
Vought Corporation
P. O. Box 225907
Dallas, Texas 75265

DTIC
S   D
JUL 1 4 1982
H

Final Report for Period September 1977 - December 1980

April 1981

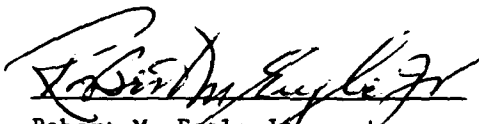Approved for public release; distribution unlimited

FLIGHT DYNAMICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
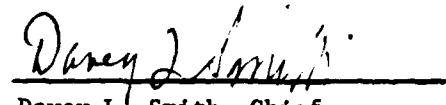WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433
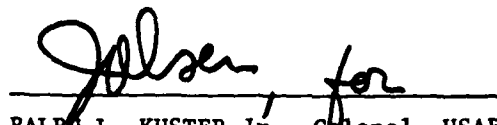
82 07 14   085

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

This technical report has been reviewed and is approved for publication.

Robert M. Engle Jr.
Project Engineer

Davey L. Smith, Chief
Structural Integrity Branch

FOR THE COMMANDER:

RALPH L. KUSTER Jr., Colonel, USAF
Chief, Structures & Dynamics Division

"If your address has changed, if you wish to be removed from our mailing list, or if the addressee is no longer employed by your organization please notify AFWAL/FIBE, W-P AFB, OH 45433 to help us maintain a current mailing list".

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFWAL-TR-81-3079	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) HANDBOOK OF FORCE MANAGEMENT METHODS		5. TYPE OF REPORT & PERIOD COVERED FINAL September 1977-December 1980
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) A.P. Berens, D.S. Morcock, K.E. Brown, R.L. Johnson, J.C. Davis, C.E. Larson, and D.J. White		8. CONTRACT OR GRANT NUMBER(s) F33615-77-C-3122
9. PERFORMING ORGANIZATION NAME AND ADDRESS University of Dayton Research Institute Dayton, Ohio 45469		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62201F 2401 0119
11. CONTROLLING OFFICE NAME AND ADDRESS Flight Dynamics Laboratory (AFWAL/FIBEC) Air Force Wright Aeronautical Laboratories Wright-Patterson Air Force Base, OH 45433		12. REPORT DATE April 1981
		13. NUMBER OF PAGES 342
14. MONITORING AGENCY NAME & ADDRESS(If different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

A.P. Berens-University of Dayton; D.S. Morcock, K.E. Brown, R.L. Johnson, and J.C. Davis-Lockheed-Georgia Company; C.E. Larson and D.J. White-Vought Corporation

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Force Management	Structural Integrity	Damage Tolerance
Structures	Structural Maintenance	Individual Aircraft
Flight Loads	Inspection Scheduling	Tracking
Structural Life Management	Data Recording	
Fatigue	Data Analysis	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Force management comprises those operations of the Air Force Aircraft Structural Integrity Program that must be conducted to ensure damage tolerance and durability throughout the useful lives of individual airplanes. More specifically, force management is the specification and direction of inspection, preventive maintenance, repairs, modifications and damage assessments required to economically prevent structural failure and preserve the strength and rigidity of airframes. This handbook presents methods for performing the complex system of data collection, processing and analysis which must be performed

DD FORM 1473 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

to provide the necessary information for planning decisions. In particular, the force management tasks are defined, organizational assignments and responsibilities are reviewed and methods of performing the functions of force structural maintenance planning, individual aircraft tracking, and loads/environment spectra surveys are presented.

FOREWORD

This is the final report of a study performed by the contractor team of the University of Dayton Research Institute, Lockheed-Georgia Company and Vought Corporation under Air Force Contract F33615-77-C-3122. The program was performed for the Air Force Wright Aeronautical Laboratories (AFWAL/FIBEC). Mr. Robert M. Engle, Jr., served as the Air Force Project Engineer during the final six months of the contract. Dr. Alan P. Berens of the University of Dayton was Program Manager for the contractor team with Mr. Douglas S. Morcock of the Lockheed-Georgia Company and Charles E. Larson of the Vought Corporation leading their company's respective efforts. The work was accomplished between September 1977 and December 1980.

This report summarizes current and near-term methods for achieving structural force management of Air Force airplanes in accordance with MIL-STD-1530A. The University of Dayton was responsible for those aspects of the problem related to data collection, processing, and analysis and for program management. Lockheed-Georgia and Vought were responsible for the application of force management methods as applied to transport/bomber and attack/fighter/trainer aircraft types, respectively.

Previous reports resulting from this contract were "Force Management Methods Task I Report-Current Methods," report number AFFDL-TR-78-183 and "Force Management Methods Task II-Volume I Summary and Analysis Considerations, Volume II Transport/Bomber Aircraft Evaluation of Potential Improved Methods, and Volume III Attack/Fighter/Trainer Aircraft Evaluations of Potential Improved Methods," report number AFWAL-TR-80-3120, Volumes I, II, and III. This final report is a distillation of the material contained in the Tasks I and II reports. The Task I report has been previously published and distributed. Copies of the Task II report can be obtained from Mr. Engle, AFWAL/FIBEC.

TABLE OF CONTENTS

LIST OF ACRONYMS

A/C	Aircraft
ACI	Analytical Condition Inspection
ACMS	Advanced Configuration Management System
AFALD	Air Force Acquisition Logistics Division
AFLC	Air Force Logistics Command
AFM	Air Force Manual
AFR	Air Force Regulation
AFRES	Air Force Reserves
AFSC	Air Force Systems Command
A/F/T	Attack/Fighter/Trainer
AFTO	Air Force Technical Order
AFWAL	Air Force Wright Aeronautical Laboratories
AGA	Air-Ground-Air
ALC	Air Logistics Center
ALDCS	Active Lift Distribution Control System
ASD	Aeronautical Systems Division
ASIMIS	Aircraft Structural Integrity Management Information System
ASIP	Aircraft Structural Integrity Program
ATC	Air Training Command
CA	Counting Accelerometer
CDB	Central Data Bank
CG	Center of Gravity
CGG	Crack Growth Gage
CIE	Controlled Interval Extension
CP	Center of Pressure
DADTA	Durability and Damage Tolerance Assessment (Analysis)
D.I.	Damage Index
DTA	Damage Tolerance Analysis
DTU	Data Transcriber Unit
FFT	Fast Fourier Transform
FSM	Force Structural Maintenance
FSMP	Force Structural Maintenance Plan
GAG	Ground-Air-Ground

DTIC
COPY
INSPECTED
3

LIST OF ACRONYMS

IASLMP	Individual Aircraft Service Life Monitoring Program
IAT	Individual Aircraft Tracking
ICAO	International Civil Aviation Organization
KCAS	Knots Calibrated Air Speed
LDG	Landings
L/ESS	Loads/Environment Spectra Survey
LH	Left Hand
LHRP	Life History Recording Program
LRU	Line Replaceable Unit
MADARS	Malfunction, Detection, Analysis and Recording System
MAI	Maneuver Activity Indicator
MCR	Multi-Channel Recorder
MDC	Maintenance Data Collection
MDS	Model/Design/Series
MFR	Manufacturer
MN	Mach Number
MSG	Maintenance Steering Group
MSL	Mean Sea Level
MSR	Mechanical Strain Recorder
NDI	Non-Destructive Inspection
n_z	Normal Acceleration
NZCG	Normal Acceleration at Center of Gravity
OPR	Office of Primary Responsibility
PDM	Programmed Depot Maintenance
PI	Peak Indicator
RECAP	Recorder Analysis Program
RH	Right Hand
R/T	Reformatter/Transcriber
SCMS	Standard Configuration Management System
SDC	Signal Data Converter
SLA	Service Life Analysis
SLM	Service Life Monitoring
SLRP	Service Life Recording Program
SPO	Systems Program Office

LIST OF ACRONYMS

T/B	Transport/Bomber
TCTO	Time Compliance Technical Order
T.O.	Technical Order or Take Off
UDD	Unit Damage Data
VGH	Velocity, Normal Acceleration, Altitude

SECTION 1

INTRODUCTION

SECTION 1
TABLE OF CONTENTS

1.0

SECTION 1
INTRODUCTION

1.1 PURPOSE

Air Force Regulation 80-13 establishes the Air Force Structural Integrity Program (ASIP) which is a set of cradle to grave actions timed "to ensure that the aircraft's Service Life Capability is at least equal to its Required Service Life." The detailed technical requirements for an ASIP are contained in MIL-STD-1530A, "Aircraft Structural Integrity Program, Airplane Requirements" and comprise five major tasks. The first three tasks are concerned with design information, design analyses and development tests, and full scale testing. The last two tasks list the requirements for ensuring damage tolerance and durability of individual aircraft during force operations of the particular aircraft type. These latter requirements are defined as force management and this handbook is directed to methods of achieving these force management objectives. For convenience of reference, Air Force Regulation 80-13 and MIL-STD-1530A are included as Appendix A.

1.2 SCOPE

Maintaining the strength, rigidity, damage tolerance, and durability of Air Force aircraft structures is dependent on the capability of the appropriate Air Force Commands to perform specific inspection, maintenance, and modification or replacement tasks at the appropriate times throughout the service life. To economically perform these tasks the Air Force must have detailed knowledge of the required actions and sufficient data to schedule inspections, repairs, and modifications. This information comprises the three primary force management elements, viz., the force structural maintenance plan, individual aircraft tracking, and the loads/environment spectra survey.

The basis for maintenance action planning is the plan required by MIL-STD-1530A and called the force structural maintenance (FSM) plan. This FSM plan identifies inspection and modification requirements, including criteria, schedules, and detailed procedures for use at field or depot level. Complete detailed information (when, where, how, and cost data, as appropriate) is included in the plan. The FSM plan is used by the Air Force to establish budgetary planning, force structure planning, and maintenance planning. The initial version of the FSM plan is based on design service life, design usage spectra, and design analyses revised to include the results of design development and full scale tests. After the aircraft is in service, the initial FSM plan is updated to reflect actual operational usage.

Under the requirements of MIL-STD-1530A, the scheduling of structural maintenance actions is based on potential flaw growth at critical locations as defined by MIL-A-83444, "Airplane Damage Tolerance Requirements." Since potential flaw length is a function of experienced stress history, and, since individual aircraft within a force can encounter large variations in usage severity, it is necessary to calculate potential flaw growth in each airplane based on its usage. The process of collecting and processing the data required in the estimation of potential crack length is defined as individual aircraft tracking (IAT).

Maintenance actions require advance planning which is dependent on projected usage of the aircraft force. When a particular aircraft force is introduced into service, the projected usage is based on design mission profiles and the stress histories that would result from these profiles. Therefore, a data collection and analysis program is required to measure the operational stress history in order to validate or update the projections of crack growth as a function of flight time that form the basis of maintenance action scheduling. This element of force management is known as the loads/environment spectra survey (L/ESS).

1-2

Due to the complex nature of the process of force management, special attention must also be directed to the problems of coordinating the technical data requirements and the responsibilities of the relevant organizations. Force management is the responsibility of the Air Force and is accomplished using a data package provided by the airframe contractor. Within the Air Force, specific responsibilities are assigned in Air Force Regulation 80-13 to the Systems Command (AFSC), the Logistics Command (AFLC) and the using commands. These roles require considerable interfacing between the organizations not only in the transfer of responsibilities and data but also in the accomplishment of the technical details of an ASIP.

While it is recognized that each aircraft system will have its own force management needs and requirements, this handbook presents guidelines and procedures which have general application. References 1 through 4 are source documents for most of the material of this handbook.

1.3 HANDBOOK DESCRIPTION

The handbook is structured to emphasize the three primary force mangement functions of force structural maintenance planning, individual aircraft tracking, and load/environment spectra surveys. Information is also presented on the background and general requirements of the force management tasks and on the definition of the roles of the organizations which implement the force management tasks. The particular arrangement of this material is as follows.

Section 2 presents a brief history of the evolution of the Air Force Aircraft Structural Integrity Program, defines the concept of structural force management, and summarizes all of the elements of the force management tasks.

Section 3 summarizes the responsibilities of the organizations which implement force management activities and discusses problems which occur at the interfaces between the organizations, functions and other Air Force systems.

Section 4 discusses the requirements of the Force Structural Maintenance Plan. In particular, it addresses structural maintenance action planning, individual aircraft maintenance requirements, the implementation of the Force Structural Maintenance Plan, the updating of the of the Plan and economic life estimation.

Section 5 presents the current and near term future methods of tracking potential crack growth in aircraft structures. The tracking requirements are defined, the tracking methods are described and briefly compared, and the implementation of the tracking function is discussed.

Section 6 presents the methods for obtaining the operational usage spectra of the loads/environment spectra survey function. The requirements are defined and the data recording, data processing, and implementation methods are described.

Appendix A contains Air Force Regulation 80-13 and MIL-STD-1530A for reference.

Appendix B presents an outline format summary of the force management elements with corresponding organizational assignments.

Appendix C is a general discussion of the large data processing requirements for achieving the Force Management objectives.

SECTION 2
BACKGROUND

SECTION 2

TABLE OF CONTENTS

2.0

SECTION 2
LIST OF FIGURES

SECTION 2

BACKGROUND

2.1 AIRCRAFT STRUCTURAL INTEGRITY PROGRAM

Fatigue failures in aircraft structure became significant during the 1950's with the widespread use of high strength metals. In response to this problem, the Air Force initiated the Aircraft Structural Integrity Program (ASIP) which required that aircraft be designed to operate under projected service loads for the service life and be tested to demonstrate a safe fatigue life of four times the service life requirements[5]*. This program was updated in 1966[6] and introduced requirements for two full-scale cyclic test articles; a parametric fatigue analysis to account for variations in individual aircraft usage; and, technique and procedures to tie structural inspection requirements into the ASIP. The concept of damage tolerance was also introduced at this time as an alternative to the safe-life design concepts.

In 1972, the ASIP requirements were documented in MIL-STD-1530[7] and introduced the concepts of durability, fracture and fatigue control, and fleet management of airframe structural integrity. The full-scale fatigue test article was required to withstand an equivalent of four service lifetimes without life limiting fatigue cracking.

The current requirements were published in 1975 as MIL-STD-1530. This revision has expanded the definitions in earlier versions and has replaced "fatigue" requirements by damage tolerance and durability requirements. In addition, the standard now establishes the scheduling of testing and modifications relative to the production schedule and defines the interaction between the basic elements of force management.

The objectives of ASIP are to:

a. Establish, evaluate, and substantiate the structural integrity (airframe strength, rigidity, damage tolerance, and durability) of the airplane.

---

*See List of References, Section 7

b.   Acquire, evaluate, and utilize operational usage data to provide a continual assessment of the in-service integrity of individual airplanes.

c.   Provide a basis for determining logistics and force planning requirements (maintenance, inspections, supplies, rotation of airplanes, system phase-out, and future force structure).

d.   Provide a basis to improve structural criteria and methods of design, evaluation, and substantiation for future airplanes.

To accomplish the ASIP requirements, five general tasks have been defined, as shown in Figure 2-1. Tasks I, II, and III provide compliance with the basic structural design require- ments of the airplane while Tasks IV and V assess the design capabilities and plan operation and maintenance requirements to utilize the design potential. Tasks IV and V comprise the elements of Force Management as addressed in this handbook.

2.2   DEFINITION AND OBJECTIVE OF STRUCTURAL FORCE MANAGEMENT

Task V, in MIL-STD-1530A, defines force management as "those operations that must be conducted by the Air Force during force operations to ensure damage tolerance and durability throughout the useful life of individual airplanes." Because this definition refers to the qualitative concepts of damage tolerance and durability, it is difficult to grasp the extent of force management.

MIL-STD-1530A also defines the following:

"Damage Tolerance. The ability of the airframe to resist failure due to the presence of flaws, cracks, or other damage for a specified period of unrepaired usage.

TASKS TO ASSESS DESIGN AND PLAN STRUCTURAL
OPERATION AND MAINTENANCE

CONTRACTOR	USAF
TASK IV	TASK V
FORCE MANAGEMENT DATA PACKAGE	FORCE MANAGEMENT
FINAL ANALYSES	LOADS/ENVIRONMENT SPECTRA SURVEY
STRENGTH SUMMARY	INDIVIDUAL AIRPLANE TRACKING DATA
FORCE STRUCTURAL MAINTENANCE PLANS	INDIVIDUAL AIRPLANE MAINTENANCE TIMES
LOADS/ENVIRONMENT SPECTRA SURVEY	STRUCTURAL MAINTENANCE RECORDS
INDIVIDUAL AIRPLANE TRACKING PROGRAM	

TASKS TO PROVIDE COMPLIANCE WITH BASIC STRUCTURAL
DESIGN REQUIREMENTS

TASK I	TASK II	TASK III
DESIGN INFORMATION	DESIGN ANALYSES AND DEVELOPMENT TESTS	FULL SCALE TESTING
ASIP MASTER PLAN	MATERIALS AND JOINT ALLOWABLES	STATIC TESTS
STRUCTURAL DESIGN CRITERIA	LOAD ANALYSIS	DURABILITY TESTS
DAMAGE TOLERANCE & DURABILITY CONTROL PLANS	DESIGN SERVICE LOADS SPECTRA	DAMAGE TOLERANCE TESTS
SELECTION MAT'LS, PROCESSES, & JOINING METHODS	DESIGN CHEMICAL/ THERMAL ENVIRONMENT SPECTRA	FLIGHT & GROUND OPERATIONS TESTS
DESIGN SERVICE LIFE AND DESIGN USAGE	STRESS ANALYSIS	SONIC TESTS
	DAMAGE TOLERANCE ANALYSIS	FLIGHT VIBRATION TESTS
	DURABILITY ANALYSIS	INTERPRETATION & EVALUATION OF TEST RESULTS
	SONIC ANALYSIS	
	VIBRATION ANALYSIS	
	FLUTTER ANALYSIS	
	NUCLEAR WEAPONS EFFECTS ANALYSIS	
	NON-NUCLEAR WEAPONS EFFECTS ANALYSIS	
	DESIGN DEVELOPMENT TESTS	

Figure 2-1. USAF Aircraft Structural Integrity Program Tasks (MIL-STD-1530A).

Durability. The ability of the airframe to resist cracking (including stress corrosion and hydrogen induced cracking), corrosion, thermal degradation, delamination, wear, and the effects of foreign object damage for a specified period of time."

From these definitions, it is obvious that damage tolerance and durability are structural qualities which are designed and produced into an airframe. Structural tests can measure the airframe damage tolerance and durability by estimating the periods of time required for excessive cracking or failure during a typical usage. It then becomes the task of force management to maintain the structure during its inherent useful life.

Therefore, the definition of Force Management can be reworded as follows:

"Force Management. The specification and direction of inspections, preventive maintenance, repairs, modifications, and damage assessments required to economically prevent structural failure and preserve the strength and rigidity of the individual airframe during its useful life."

The basic objective of ASIP is to ensure operational safety and readiness of the airframe. Force Management objectives are to:

1. Prevent structural failure through an effective maintenance program of inspections, repairs, and modifications.

2. Preserve structural strength and rigidity through an effective preventive maintenance program of environmental protection and economic repair or replacement of deteriorating parts.

3. Minimize structural maintenance costs by eliminating unnecessary structural maintenance actions through effective application of data on test and operational failure modes and data on individual aircraft usage.

4. Provide a basis for planning of system phase-out and future force structure.

2.3 ELEMENTS OF FORCE MANAGEMENT

To meet the force management objectives, specific contractor and Air Force tasks have been defined in MIL-STD-1530A. These tasks are comprised of the elements listed in Figure 2-2.

The five elements which constitute the Task IV Force Management Data Package are performed by the contractor to provide the Air Force with the procedures and data required to manage subsequent fleet operations and maintenance. To avoid duplication, the contractor is strongly encouraged to utilize, where possible, government furnished equipment, facilities, and personnel to acquire and process operational data during these tasks. It is intended that performance of Task IV will lead to a smooth transition into the Air Force operation during Task V.

The four elements of Task V Force Management are performed by the Air Force (with contractor support where required) to provide maintenance planning and structural integrity information for the remainder of the aircraft service life. The Force Management elements are keyed to the projection of maintenance based on individual aircraft usage and to detect when changes in fleet operations dictate review of analytical monitoring procedures developed in Task IV. The diagram in Figure 2-3 indicates the approximate sequence of the Force Management elements.

The following paragraphs briefly describe the Force Management elements as defined in MIL-STD-1530A. Appendix B presents a summary of the Force Management elements in outline form which lists the work tasks, the work and management responsibilities and the required input and output.

2.3.1 Final Analysis (Force Management Data Package)

The final analysis will update the design analyses to incorporate the results of the developmental and full-scale tests and, later, to incorporate the baseline operational spectra. These analyses will also develop inspection and repair criteria for use in the force structural maintenance plan.

CONTRACTOR	USAF
TASK IV	**TASK V**
FORCE MANAGEMENT DATA PACKAGE	**FORCE MANAGEMENT**

1. Final Analysis	1. L/ESS
-Initial Update of Analysis	-Data Acquisition Procedures
-Final Update of Analysis	-Data Acquisition Services
-Inspection and Repair Criteria	-Training
2. Strength Summary	-Data Processing Services
3. Force Structural Maintenance Plan	2. Individual A/C Tracking Program
-Initial FSM Plan	-Data Acquisition Procedures
-Updated FSM Plan	-Data Acquisition Services
4. L/ESS Data Analysis	-Training
-Data Acquisition Provisions	-Data Processing Services
-Data Processing Provisions	3. Individual A/C Maintenance Times
-Interim Processing Services	4. Structural Maintenance Records
-Baseline Operational Spectra	
5. Individual A/C Tracking Program	
-Tracking Analysis Method	
-Data Acquisition Provisions	

Figure 2-2. Force Management Elements.

2-6

SEQUENCE

TASK

STRENGTH SUMMARY

LOADS/ENVIRONMENT SURVEY

FINAL ANALYSES

FORCE STRUCTURAL MAINTENANCE PLAN

INDIVIDUAL AIRPLANE TRACKING

INDIVIDUAL AIRPLANE MAINTENANCE

STRUCTURAL MAINTENANCE RECORDS

Figure 2-3. Sequence of Force Management Elements.

2.3.1.1 Initial Update of Analysis

During the design analyses, input loads and structural transfer functions are based on accepted analytical procedures and empirical data from wind tunnel or other scaled tests. The final proof of these analyses is the measurement of airframe response to design load conditions during full-scale testing. Because of the time required to fabricate and instrument full-scale test articles and to conduct the required tests, the test results are not normally available until during the production stage of the airframe. This data is used to update the analyses prior to developing the structural maintenance plan.

2.3.1.2 Final Update of Analysis

After the fleet has been operational for a significant period of time, a baseline operational spectra (in the form of stress sequences at critical locations) is derived from recorded operational data. The damage tolerance and durability analysis will be repeated using the baseline operational spectra and this assessment will result in *inspection and modification* requirements for the airframe and an economic life estimate based on projected wearout of the structure.

2.3.1.3 Development of Inspection and Repair Criteria

Based on the analysis, rational criteria must be developed to guide inspection and repair limits and procedures. The criteria must consider types of material and construction, reasonable limits of repair, critical crack lengths, and inspection capabilities to define inspection criteria and repair procedures.

2.3.2 Strength Summary

This summary will indicate the airframe limits and capabilities in terms of operational parameters (airspeed, normal acceleration,center of gravity,location, and weight). The summary

will include a structural description including arrangement, materials, design conditions, damage tolerance and durability critical areas, and margins of safety. Backup documentation will be referenced.

2.3.3   Force Structural Maintenance Plan

The force structural maintenance plan shall form the basis for the airframe portions of the TO 1X-XX-6 Aircraft Scheduled Inspections and Maintenance Requirements Manual, the TO 1X-XX-36 Nondestructive Inspection Manual, and the TO 1X-XX-3 Structural Repair Manual. The plan will specify what structural inspections and modifications are required; when they should be accomplished; how inspections, modifications, and repairs should be accomplished; critical structural locations; and cost data for repairs and inspections where trade off decisions may be appropriate. The Air Force will use this plan for budgetary planning, force structure planning, and maintenance planning.

2.3.3.1   Initial Force Structural Maintenance Plan

This plan will be based on the design service life and the results of the initial update of the final analysis.

2.3.3.2   Updated Force Structural Maintenance Plan

This update will be based on the final update of the analysis and the baseline operational spectra. Additional updates will be made any time the force operation uncovers new critical structural areas or significant changes in the operational spectra.

2.3.4   Loads/Environment Spectra Survey

Since the actual usage of the aircraft may impose a stress environment different from that predicted during design, an early assessment of the operational usage is obtained through the loads/environment spectra survey (L/ESS). This element of force management consists of monitoring the time histories of the relevant flight parameters during operational flights so that an

assessment of stress histories at critical locations can be made. Since the operational usage of an airplane can change, the Air Force also has the responsibility for reinstating (if necessary) the L/ESS and initiating an update of the baseline operational spectra.

2.3.4.1   Data Acquisition Provisions

Responsibility for determining the required parameters to be monitored, the number of aircraft to be instrumented, the length of recording period, and the instrumentation system belong to the airframe manufacturer. Since data acquisition begins with delivery to the Air Force of the first operational aircraft, the L/ESS program should be initiated during the design and development phases. This initial planning will provide an efficient deployment of the sensors and data recording devices on the aircraft. Depending on aircraft type, intended usage, and critical points, the instrumentation system selected may also be used for the individual aircraft tracking program.

2.3.4.2   Data Processing Provisions

The airframe contractor has the responsibility to design a data processing system that is compatible with the Air Force capabilities of the Aircraft Structural Integrity Management Information System (ASIMIS). For the initial L/ESS the contractor is also responsible for performing those aspects of the data processing which are outside the scope of approved capabilities which exist within the Air Force at ASIMIS. The Air Force will perform reformatting/transcribing functions and data editing to ensure the quality of the data.

2.3.4.3   Baseline Operational Spectra

When a statistically adequate sample of data are recorded (representative of the types of usage planned for the aircraft), the airframe contractor will analyze the data and develop the baseline operational spectra. The durability and damage tolerance analyses will be updated using the baseline operational spectra if different from the design spectra.

2-10

2.3.5   Individual Airplane Tracking Program

A significant part of force management is the provision to schedule maintenance actions for each individual airplane based on its usage to improve safety and readiness and to reduce costs. The objective of individual airplane tracking is to monitor the usage of each individual airplane and to provide structural inspection and maintenance schedules based on predicted flaw growth. Provisions will be made to track, in addition to airplanes, major serialized structural components which are likely to be removed, inspected or repaired, and reinstalled on a different airplane.

2.3.5.1   Tracking Analysis Method

A tracking method will be developed which is compatible with the damage tolerance and durability analysis results. The method will determine which airplane usage parameters must be monitored to permit adjustment of inspection intervals and modification and repair times. Since the tracking program will be operated by the Air Force, data processing and analysis requirements must be compatible with the Air Force data analysis system.

2.3.5.2   Data Acquisition Provisions

A data collection system will be selected to monitor and record the required tracking data on each aircraft. The least expensive data collection system which will record the required parameters at the required level of accuracy will be selected.

2.3.6   Individual Airplane Maintenance Times

By using the force structural maintenance plan and the recorded individual aircraft usage data, structural maintenance times will be projected for each airplane.

2.3.7 Structural Maintenance Records

The Air Force will maintain records of significant structural maintenance actions for each airplane. The records will be made available to the airplane usage tracking activity so future maintenance projections can account for previous inspection findings, repair actions, and structural configuration changes.

2.4 FORCE MANAGEMENT OPERATION

During the operational phase of an aircraft system, the interaction between the individual force management elements can be interpreted as in Figure 2-4. The following description of the force management system assumes that the final analyses are based on stable operational spectra as determined by the L/ESS program. The ASIP Office of Primary Responsibility (OPR) for the weapon system is introduced as the prime recipient of data and the decision maker with respect to maintenance actions and scheduling.

From the viewpoint of the force management process, a key requirement of the Final Analysis is the determination of inspection and repair time for structural components and assemblies based on a quantitative approach. To meet this requirement, the analysis must identify all critical areas as well as the damage limit and damage growth rate in each critical area. Therefore, as part of the durability and damage tolerance analysis, damage size is calculated as a function of time in representative stress environments. This result is typically viewed as a plot of potential crack length versus "baseline" hours. When the initial crack size is assumed to be the largest that could pass the manufacturer's quality control system, the curve is used to determine inspection limits for safety. Durability is assessed in terms of time required for an average equivalent initial flaw or a distribution of equivalent initial flaws to grow to a size indicative of widespread cracking.
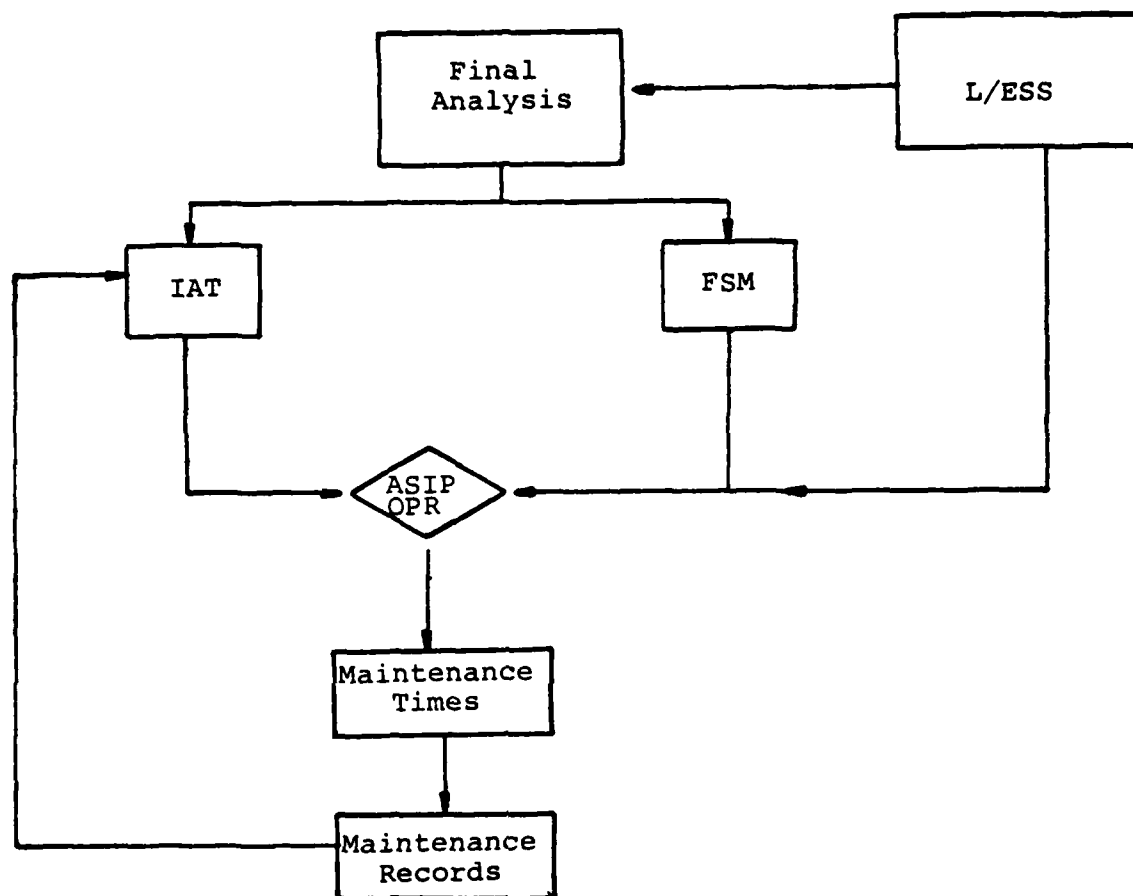
Figure 2-4. Flow Diagram for Force Management Operation.

A crack length-flight time curve is calculated for each critical area and is based on the operational stress sequences as determined during the L/ESS. Such curves provide basic information required in the development of the Force Structural Maintenance Plan (FSM). They are based, however, on average usage in some stratification of the entire force and, are representative of an average airplane in the stratification. To ensure the integrity of individual airplanes, the Individual Aircraft Tracking (IAT) program monitors the potential crack length at the critical locations based on the stress environment each airplane experiences. While there are many methods for performing the IAT function (Section 5) all require at least some data from the durability and damage tolerance analyses.

The FSM Plan and the IAT results are the primary data sources on which the ASIP OPR makes decisions. The FSM identifies the inspection, modification and cost requirements of the average airframe and forms the basis for maintenance, budgeting, and perhaps operations planning. Output from the IAT program provides the data to schedule maintenance actions on specific airplanes as determined by the growth of potential cracks at the critical locations. Given a maintenance action has occurred, feedback is required to update the maintenance records and to reset (if appropriate) initial crack sizes in the IAT program.

The L/ESS function is shown as meeting two objectives: providing the operational stress sequences which define average usage for the final analyses and providing a continuous base of data to the ASIP OPR in order to detect usage changes and to provide data summaries of flight operations. These data can serve to trigger the need for an update of the final analyses and to identify usages which are particularly damaging. In the latter case, the ASIP OPR may be able to influence maintenance scheduling by arranging, for example, to have high damage aircraft avoid high damage operations.

This simplified view of the force management plan in operation emphasizes the importance of the Final Analysis (and implies the need for subsequent updates if usage, inspection methods, inspection findings, configuration, or analysis methods and criteria change). Further, since the FSM is a relatively static set of information, only the IAT has a significant function in supplying information to the ASIP OPR on a continuing basis. While it is recognized that the continuous data from a sample of the force obtained in the L/ESS has uses for other than its primary objective, it can also be recognized that such data may not be required for all aircraft types.

SECTION 3

FORCE MANAGEMENT IMPLEMENTATION

SECTION 3

TABLE OF CONTENTS

SECTION 3
LIST OF FIGURES

SECTION 3

FORCE MANAGEMENT IMPLEMENTATION

The implementation of the Force Management Tasks of MIL-STD-1530A requires the coordinated activities and management of several organizations. This section presents a summary of these responsibilities and discusses problems which can occur at the interfaces between the organizations during the performance of the force management operations.

3.1 MAJOR ROLES AND MANAGEMENT RESPONSIBILITIES

Air Force Regulation 80-13 assigns management and task responsibilities for all ASIP requirements. The following paragraphs summarize only those responsibilties which are primarily related to the Force Management Tasks of MIL-STD-1530A. Since program management for a system will be transferred from the Air Force Systems Command (ASFC) to the Air Force Logistics Command (AFLC), ASIP management responsibility is also transferred. Therefore, certain responsibilities are listed under both commands and it should be understood that the timing of specific changes are dependent on the particular AFSC/AFLC Program Management Responsibility Transfer Plan.

The work and management responsibilities for the Force Management tasks are also identified in the force management element breakdown of Appendix B. Figure 3-1 presents a summary of the organizational responsibility for each of the nine Force Management Elements defined in Figure 2-2.

3.1.1 AFSC/Aeronautical Systems Division (ASD)

Air Force Regulation 80-13 Paragraph 12 specifies AFSC responsibilities in ASIP programs. Each aircraft system being acquired has a designated program manager within ASD and all aspects of ASIP are his responsibilities until transferred to the designated AFLC Air Logistics Center (AFLC/ALC). The design, development, test verification and force management data package are managed and funded by ASD. In particular, ASD selects the type and number of

3-1

Force Management Element	Management Responsibility	Work Responsibility
1. Final Analysis	AFSC/ASD	Contractor
2. Strength Summary	AFSC/ASD	Contractor
3. Force Structural Maintenance Plan	AFSC/ASD	Contractor
4. L/ESS Data Package (Task IV)	AFSC/ASD (ASIMIS)	Contractor
5. IAT Data Package (Task IV)	AFSC/ASD	Contractor
6. L/ESS (Task V)	AFSC/ASD or AFLC/ALC	
a) Data Acquisition Procedures		AFSC/ASD
b) Data Acquisition Services		Operating Command
c) Training		AFSC/ASD,AFLC/ALC and Operating Commands
d) Data Processing		AFLC/ASIMIS
e) Data Evaluation		AFSC/ASD or AFLC/ALC
7. IAT (Task V)	AFSC/ASD or AFLC/ALC	
a) Data Acquisition Procedures		AFSC/ASD
b) Data Acquisition Services		Operating Command
c) Training		AFSC/ASD,AFLC/ALC and Operating Commands
d) Data Processing		AFLC/ASIMIS
e) Data Evaluation		AFSC/ASD or AFLC/ALC
8. Individual Aircraft Maintenance Times	AFLC/ALC	AFLC/ALC
9. Structural Maintenance Records	AFLC/ALC	AFLC/ALC and Operating Commands

Figure 3.1. Organizational Responsibilities for Force Management Elements.

recorder systems and plans, develops and manages the data collection programs and required computer software to achieve the Force Management function. For all elements of systems development having contractor involvement, ASD has the contractual funding and management functions. The depth of the system requirements activity and technical direction or monitoring varies with the complexity of the data system, the experience of the personnel, and the degree of interface considered necessary to assure an effective transfer. Until transfer to AFLC, ASD is responsible for the performance of the Task V Force Management elements.

In addition to its role during the ASIP development stage, ASD is also assigned responsibility for coordination with and continued support for the relevant AFLC/ALC. ASD must approve the use of non-standard data acquisition systems. Finally, ASD is jointly responsible for the maintenance and revision of MIL-STD-1530A and appropriate military specifications, the development of advanced data reduction and analysis techniques for evaluation of operational usage and fleet experience data, and the development of structural design criteria and methods for evaluating and substantiating airframe safety and durability.

3.1.2   AFSC/Air Force Wright Aeronautical Laboratories (AFWAL)

AFWAL's Force Management responsibilities are not directed to specific aircraft systems but rather to equipment, analyses methods, and data which are applicable to all systems. AFWAL is given responsibility for developing the recorder systems and equipment which can be used to meet the L/ESS and IAT functions. These hardware developments are to be made independent of any aircraft development program. In addition, in conjunction with ASD, AFWAL has the responsibility to develop advanced data reduction processes, analysis techniques, design criteria, and airframe safety and durability methods for future aircraft.

3.1.3 AFLC/Air Logistics Center (ALC)

For a given weapons system, the primary function of the AFLC is to provide support to the using commands which will produce safe, cost-effective, operational readiness of the system. This includes scheduling and accomplishing force structural maintenance actions, and specifying maintenance and data acquisition actions to be performed by the using commands. AFLC responsibilities are specified in Paragraphs 13 and 14 of Air Force Reg. 80-13.

The designated ALC for a weapon system will identify an ASIP manager who updates the ASIP Master Plan yearly, obtains concurrence from using commands, and budgets for, funds, and implements the approved ASIP. The performance of these functions will require ALC involvement in the management and performance of the individual aircraft tracking (IAT) function, the loads/ environment spectra survey (L/ESS) function, the definition of individual aircraft maintenance times and the updating of the structural maintenance records for the force. The ASIP manager ensures that accurate and timely information is being obtained from the data collection and analysis portion of the aircraft flight data recorder program and that quarterly reports of data quality are made.

3.1.4 AFLC/Aircraft Structural Integrity Management Information System (ASIMIS)

The central AFLC agency for processing, analyzing, and storing aircraft structural integrity data is located at the Oklahoma City ALC (Code OCALC/AIA) and is known as the Aircraft Structural Integrity Management Information System (ASIMIS). ASIMIS receives, reduces, and processes data from airborne flight data recorders, individual aircraft tracking records and forms, IAT monitoring devices, and applicable maintenance data collection systems. To ensure compatibility, ASIMIS also provides support as necessary during the preparation of the force management data package.

3.1.5 AFLC/Acquisition Logistics Division (AFALD)

The Acquisition Logistics Division defines the AFLC focal point while the ASIP management is under control of the AFSC. The designated focal point coordinates all force management activities between AFSC and AFLC agencies and ensures that lessons learned from operational aircraft are considered in the ASIP of the subject aircraft. ALD also reviews and coordinates proposed revisions to MIL-STD-1530A.

3.1.6 Operating Commands

The responsibilities of the operating commands are stated in paragraph 15 of AF Regulation 80-13. These are (1) to provide data on system utilization, operational usage and fleet experience; (2) to notify the ASIP manager of planned changes in operations from those which were used in scheduling maintenance actions; (3) to install, operate, and maintain ASIP equipment, to collect data in accordance with instructions and to maintain records which demonstrate compliance with data recording objectives; and (4) to train personnel and recommend changes to ensure acceptable data quality.

3.1.7 Airframe Manufacturer

The entire Force Management data package, Task IV of MIL-STD-1530A, is produced by the contractor and serves as the initial data base for Force Management (Task V) activities. The data package uses the results of the design, analysis, and test activities of Tasks I-III. The contractor performs all analyses, prepares all computer programs and writes all required reports as required by the elements listed under Task IV of Figure 2.2 and described in paragraph 2.3. The detailed tasks and data items to perform the elements are as specified in the contracts for the particular weapons system. Contractor involvement may also be required for Task V.

3.2 ORGANIZATIONAL INTERFACES

Figure 3.2 displays the interfaces between the organizations which have assigned responsibilities in the execution of force management activities. In addition to the organizations whose responsibilities are defined in paragraph 3.1, the figure identifies a structural review committee and the AFLC Maintenance Data System (Code AFLC/LOL) as force management organizations. AFLC/LOL is assigned the responsibility of collecting and processing maintenance data for the Air Force. The force management role of AFLC/LOL is to provide the results of inspection and repair activities to the ASIP manager so that potential crack lengths can be updated for individual aircraft or specific components. This reporting system is discussed in paragraph 3.2.3. If major structural problems develop on a particular system, a structural review is formed from AFSC structures experts to aid the System Manager. This organization is shown in Figure 3.2 but may not be required for all systems.

Part way through the life of a system, the responsibility for ASIP is transferred from AFSC/ASD to the AFLC/ALC System Manager. This transition, indicated by the dashed lines of Figure 3-2, generally coincides with the completion of airframe deliveries and has in the past been the source of difficulty in the implementation of the force management tasks. The following paragraphs discuss this major interface and also define the interfaces between force management and the Technical Order System and the AFM 66-1 maintenance data recording system.

3.2.1 Interface Between AFSC/ASD and AFLC/ALC

To date, each aircraft force management program has been transferred from AFSC to AFLC in its own unique manner. There are, however, some general similarities. In each case, the force management responsibilities of the program elements defined in Section 2 were not transferred at one point in time, but rather were transitioned piecemeal and in some cases were jointly held by AFSC and AFLC. Problems arising from this arrangement were, in general, traceable to the lack of a definite
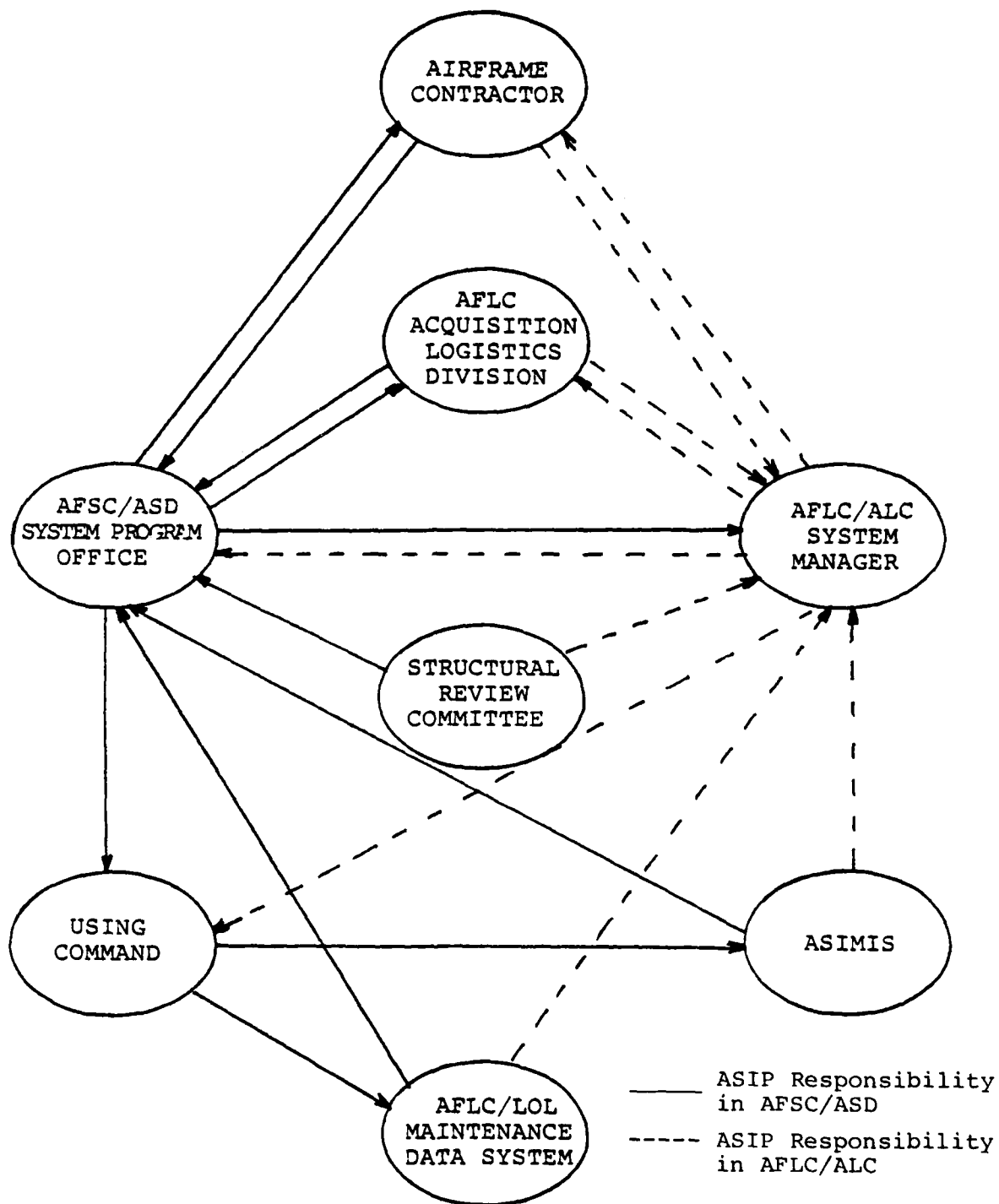
Figure 3.2. Interface of Force Management Organizations.

assignment of management responsibility for each force management task. This resulted in neither AFSC nor AFLC assuming the work task responsibility, or both commands attempting to assume responsibility, and the airframe contractor having to be responsible to two commands for task guidance and approval.

The key ingredient for a smooth transition of force management between AFSC and AFLC is to have well defined work tasks (elements) with the assigned management responsibilities and for the responsible command to be given the resources to carry them out. To provide a smoother transition of the Force Management the ALC structures engineers should be made a part of the decision-making process within the ASD System Program Office (SPO). Periodic (yearly) ASD-AFLC-contractor meetings to discuss ASIP activities and interfaces should be conducted throughout the entire program.

Methods for smooth transition must also recognize the interrelationship of ASD and AFLC in the following situations:

a) The data from Task V and in-depth evaluations of these data are valuable to ASD in the design specification for future aircraft and in updating ASIP and Military Specification requirements. Continuing communication between ASD and AFLC regarding these needs, and response by AFLC beyond its own Force Management requirements, are necessary for overall benefit to the ASIP. Periodic updates of the Service Life Analysis should be planned and ASD should be kept aware of the results.

b) When ASD updates the ASIP specifications, a new set of requirements is imposed on AFLC which must be applied to its existing aircraft and existing Force Management systems. For a major change, such as the inclusion of crack growth durability and damage tolerance evaluations, significant program management, funding, and technical direction must be provided. For example, in the C-141 durability and damage tolerance assessments (DADTA), AFLC provided program management and funding while AFLC and (primarily) ASD jointly provided technical direction. This example illustrates the fact both ASD and AFLC involvement are needed for appropriate implementation of revised ASIP requirements to existing programs.

3-8

c) Completion of the Task II structural test program and the Task IV final analyses are intended prior to handoff from ASD to AFLC. However, delays due to test damage or extensions in the test program can result in the test schedule lagging the hand-off by a number of years. This can occur even for "fly-before-buy" contracts since production go-ahead and deliveries may be determined by need for the aircraft rather than by test progress. Flexibility at the ASD-AFLC boundary is necessary to produce the best program under these circumstances.

The following potential transition problems are considered likely to occur.

a) Test program extends beyond handoff date

b) Final analyses not completed when aircraft goes into service.

c) Modifications found necessary by tests and analyses must be accomplished in service.

d) FSM manuals not completed when aircraft enter service.

e) L/ESS equipment or computer programs not operational when required.

f) IAT system not operational when required.

g) Changes in operational or structural requirements.

In addition, the following potential problems may arise during service operations after transition, requiring both ASD and AFLC involvement.

a) Change in ASIP requirements which require reassessment with ASD involvement.

b) Major change in aircraft configuration.

c) Major change in aircraft usage.

d) Major change in technology for FSM, IAT or L/ESS functions.

3.2.2 Interface Between Force Management and The Technical Order System

The Air Force Technical Order (T.O.) is the official tool for force management implementation and update. Initial contractor requirements usually include the preparation of the basic T.O. manuals as a part of the aircraft design/development contract. In addition, results from ongoing structural test or analysis programs (also foreign/commercial aircraft data, where available) are used to generate recommendations regarding update of existing requirements. The role of the contractor in providing input to this process is primarily a function of its contractual involvement with the aircraft System Manager (AFSC or AFLC) at the time, and is secondary to USAF. Responsibility for acceptance or rejection of recommended actions lies with the Air Force System Manager.

ASD responsibilities include providing the operational manuals for the weapons systems being developed. For transport aircraft, for example, these manuals include:

T.O. 1C-XX-1	Flight Manual
-2	Maintenance Instructions
-3	Structural Repair Instructions
-4	Parts Catalog
-06	Work Unit Code Manual
-6	Inspection Requirements
-9	Cargo Loading Manual
-17	Storage of Aircraft
-23	Corrosion Control
-36	Non-Destructive Inspection Manual

These manuals are generally produced by the contractor as part of the developmental contract. Subsequent revisions are accomplished by contracts from the Air Logistics Center, or by personnel within the Air Logistics Center.

All scheduled periodic maintenance for a force is specified in the T.O. -6 technical order for the system. The T.O. -6 comprises a control document listing the requirements and sets of workcards corresponding to specific scheduled inspections. In addition, one-time scheduled maintenance and modifications may be specified and scheduled by a Time Compliance Technical Order (TCTO). The TCTO describes the maintenance requirement, the procedure to be used, and the schedule for complying with the requirement. In some applications, a TCTO may specify a requirement and schedule by individual airplanes.

3.2.3   Interface Between Force Management and the AFM 66-1 System

Air Force Regulation 66-14 contains an outline of general maintenance program objectives, concepts, policies and responsibilities. The AFM 66-1 maintenance data recording system implements the provisions of AFR 66-14 which pertain to organizational and intermediate level maintenance operations. AFM 66-1 is based on "centralized management of standard maintenance organizations" and sets up detailed chains of command for Air Force FSM program implementation. From the contractor's point of view, the prime function of the AFM 66-1 system is to provide a standardized data bank which contains results from field and depot level maintenance activities. This is accomplished through the use of the T.O.-06 work unit codes, which are used to identify the location, type, and disposition of structural defects. This information, in combination with IAT results, is intended to provide a feedback mechanism for determining the effectiveness of defined FSM operations. In practice, however, the AFM 66-1 output is often inadequate or inaccurate, due to vague or generalized location codes or faulty record keeping. This feedback loop is an integral part of productive FSM programs and the whole force management program can be affected by the lack of complete, accurate structural data.

Airplane maintenance reporting requirements are generally specified in the T.O. 00-20-X Technical Order series. The following paragraphs describe several of the reporting requirements.

3-11

3.2.3.1 Maintenance Data Collection (MDC)

The MDC system requirements are contained in TO 00-20-2. The objectives of the MDC system are to collect, store, and retrieve data for all base level maintenance and for depot level maintenance when specified by Headquarters AFLC or USAF. The data is collected on AFTO Forms 349 or 350. In general, these forms contain an identification of the airplane and its flight time, an identification of the engine or part, the inspection or work performed, any discrepancy and action taken, and the aircraft downtime and maintenance hours expended. A considerable number of entries are coded and descriptive information is generally not sufficient to describe structural defects, but can be useful as an indicator of "hot spots".

3.2.3.2 Configuration Management Systems

The SCMS (Standard Configuration Management System) and the ACMS (Advanced Configuration Management System) for reporting status and compliance of Time Compliance Technical Orders (TCTO) are described in TO 00-20-4. The SCMS monitors TCTO's against end items (airplanes) and provides monthly reports indicating the status of unaccomplished TCTO's and the compliance with accomplished TCTO's. The ACMS reports similar data for both end items (airplanes) and selected serialized components, both installed and uninstalled. The selected serialized components are identified by an asterisk (*) in the airplane work unit code manual (-06 Technical Order).

3.2.3.3 Historical Records

Certain maintenance actions and data are required to be entered in the airplane and component historical records which are stored with the equipment. Requirements and procedures for maintaining these records are contained in TO 00-20-5. Permanent records are entered on an AFTO Form 95 and will include all significant maintenance actions to the airplane as well as to those specific components designated in Section II, Part D of the airplane to TO-6 technical order.

Example Entries on Form 95 for the C-5
aircraft included the following structures entries:

>   Replacement of wings and stabilizers
>   Severe corrosion and required treatment
>   Information on accidents and incidents
>   Emergency Depot maintenance
>   TCTO compliance
>   Overstresses and hard landings
>   Replacement of time change components
>   Major landing gear maintenance
>   C-5A pylon removal
>   Fuel leak repairs
>   Engine and engine component replacement

3.3   DATA ELEMENT INTERFACES

Figure 3-3 illustrates the interface between the various
force management data elements during the operational phase of
the aircraft life. The L/ESS program is designed to feed opera-
tional stress spectra into the update of the tracking analysis
and into periodic Service Life Analyses (SLA) and durability and
damage tolerance assessments (DADTA). These updated analyses then
feed the IAT program and are used to generate an updated Force
Structural Maintenance (FSM) plan. The IAT and FSM plan then
provide individual aircraft inspection and modification scheduling.
The average usage and variability in the IAT data must be con-
sidered in the SLA and DADTA. The FSM critical areas and defect
size limits must be considered in the development of the IAT
analysis.

The major problem in interfacing the various force management
data elements is the timing. The L/ESS design must be completed
for instrumentation in the first production airplanes but the design
must be compatible with the IAT and FSM plan which tend to develop
later. The timing of the L/ESS data flow and the analyses updates
is unclear and is generally left to the initiative of the system
manager. Generally, the update of the analyses is performed by the
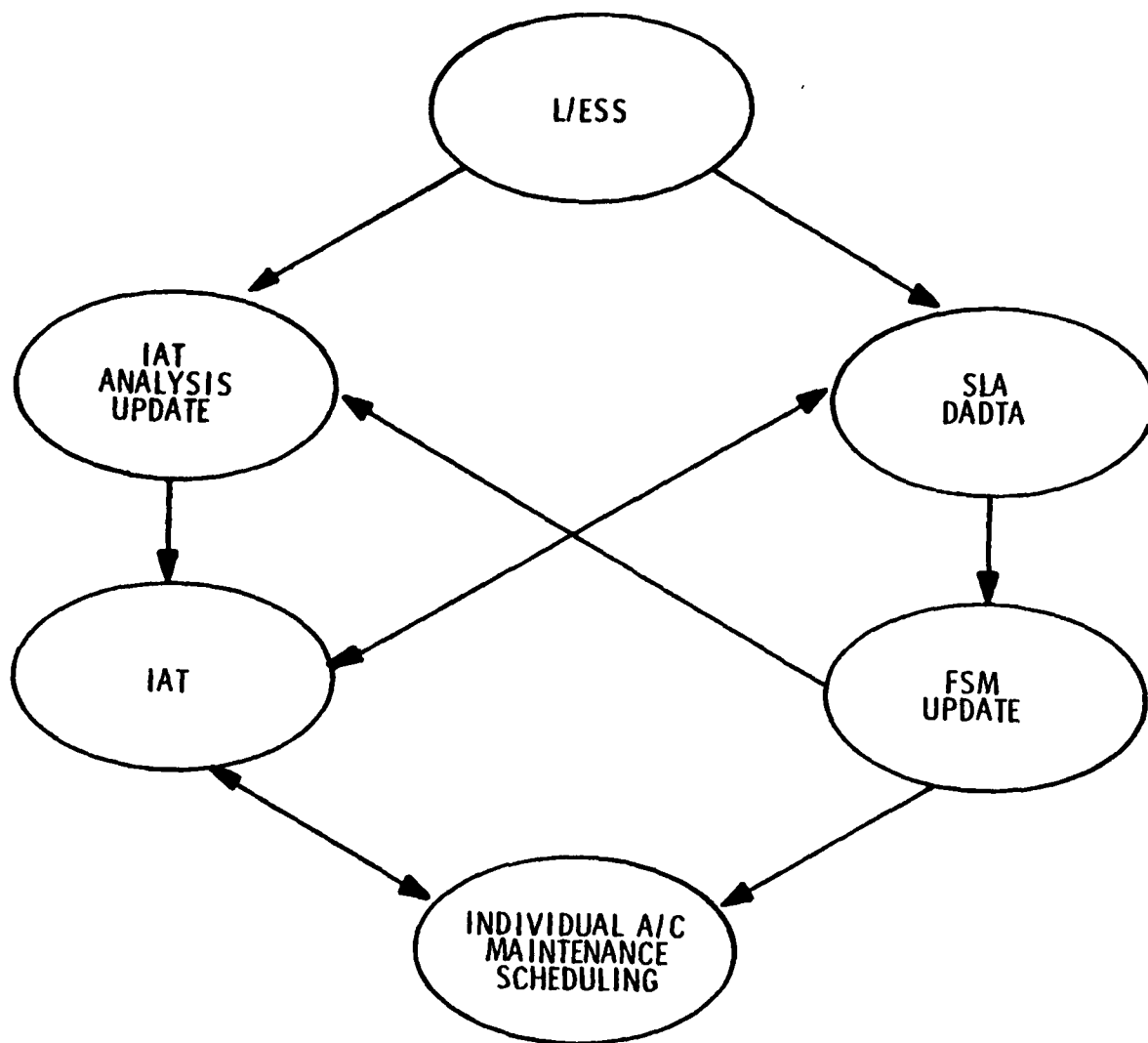airframe contractor under contract to the system manager.

Figure 3.3. Interfaces of Force Management Data Elements.

3.4   POTENTIAL PROBLEM AREAS

While there are potential problem areas associated with each of the force management tasks, several problem areas are generally applicable to the entire process. These are discussed in the following paragraphs.

3.4.1   Hardware/Procedure Development

The existing tracking programs are providing the Air Force with analytical cumulative damage indices for use in force management operations. These indices reflect changes in utilization severity of each service aircraft and provide an 'indicator' for establishing force inspection times for safe operations. However, the Air Force is much more concerned about systems and engine reliability than they are about airframe problems. Thus, with few problems, airframe structural programs are given low priority, and low percentage data return for the IAT and L/ESS programs is likely to result. Future IAT programs should investigate methods to improve the data return from force operations.

In the ideal situation, such as described in paragraph 5.4.5.2 of MIL-STD-1530A, the individual aircraft tracking recording system selected is one that is as simple as possible to support the tracking analysis method developed by the contractor. In theory this would have been the correct sequence in establishing the most efficient method of tracking. However, in almost every case of aircraft tracking development, the tracking methods and onboard instrumentation have been designated and sometimes even gathering operational data long before the required fatigue/ durability/damage tolerance analyses have begun. Without knowing the critical structural locations or even how damage is going to be tracked at these points, it is improbable that the optimum flight measurements or collection procedures were chosen.

3-15

In like manner, the choice of the L/ESS recording equipment and the parameters to be measured are generally chosen long before the contractor's analysis has determined what would be the optimum. In most cases, the decision has been to record "everything" with the hope that the methods to be developed will have enough to work with. With these parameters available, the analysis method has been tuned to require use of all of them, resulting in a complicated collection, reduction, and analysis program. Unneeded complication reduces the reliability of the system and can lead to low capture rates.

3.4.2 Data Reduction Procedures

Another potential problem is that left to themselves and ASD, without good coordination with ALC and ASIMIS, the airframe contractor may devise data collection, reduction, and analysis methods for IAT and L/ESS that are difficult and expensive to implement.

In reviewing data processing software which was procured from the airframe contractor without prior review by ASIMIS, the following problem areas were identified.

a) Inadequate editing checks. Edit programs pass gross errors which are not detected before the major part of the processing is completed.

b) Too severe editing checks. Edit programs will not pass as much as 60 percent of the data which must then be manually edited before further processing.

c) Special equipment requirements. Some programs require equipment which is unavailable at ASIMIS.

d) Inefficient data flow. Some software systems schedule edit checks too late in the processing so that the correction of errors requires rerunning all of the software steps. Some programs require too many normal operations late in the data flow.

e) Inflexible data flow. Many systems have little or no error correction capability at a late stage so that an error in a single entry of the data file may require reprocessing of the entire file.

Improved software systems require the use of qualified data base management programmers for software development.

Data yield can be improved by more direct communications between ASIMIS and the operating units. This would result in more accurate description of problems and would reduce the time between equipment malfunction and correction. In addition, field test equipment should be deployed at field level to improve the diagnostic capability for the recorder equipment.

Since structural technology is changing rapidly, any analytical system must retain the basic usage data (segment data and segment sequence) because it is very likely that any calculations will have to be revised a time or two in the future due to technology updates. For example such major areas as retardation and relaxation between flights, and what type of ground-air-ground or transition cycle to use are yet to be resolved for transport/ bomber type aircraft. Programs investigating these areas could require several years to complete.

The past and present history data of the individual aircraft monitoring programs generally do not include specific flight sequence and other data presently considered necessary for crack growth tracking. Therefore, reconstruction of the effects of operations to date must fill in this information in some analytical manner if such effects must be accounted for by the tracking system.

3.4.3 Structural Engineering/Maintenance Interface

The last observation concerns the interface between the IAT program and the force structural maintenance scheduling as indicated in Figure 3.4. A good, working relationship should be sought between these functions. The maintenance engineers do not know
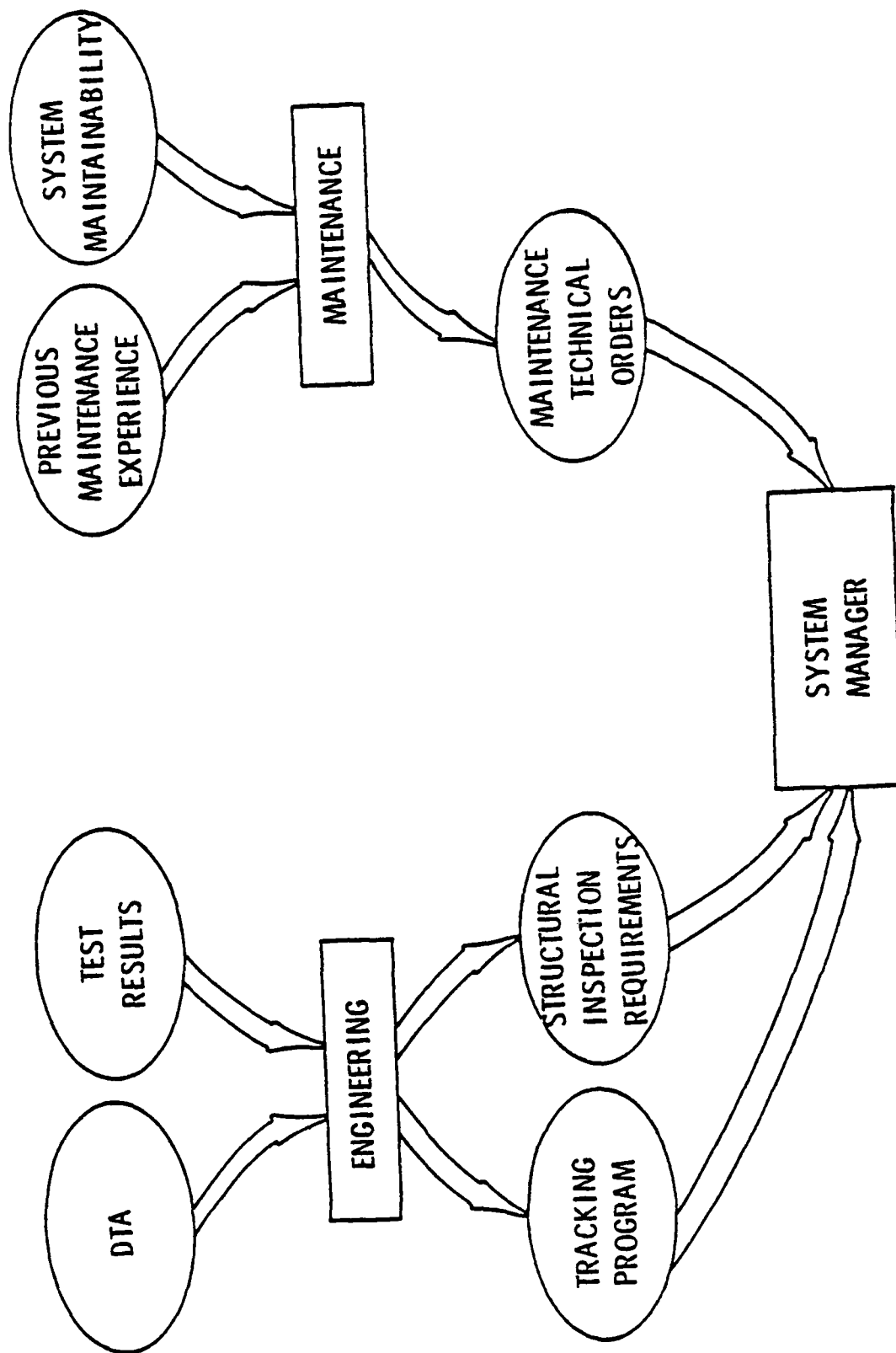
Figure 3.4. Engineering/Maintenance Interface.

how to effectively use the available IAT data in their scheduling function. In some past cases the IAT information had no impact on FSM. Conversely, part of the problem is that the structural engineers developing the methods of FSM generally do not fully understand the maintenance scheduling and reporting procedures. The result is that the system manager may end up with a set of IAT output which is incompatible with the aircraft structural maintenance program.

SECTION 4

FORCE STRUCTURAL MAINTENANCE PLAN

SECTION 4

TABLE OF CONTENTS

SECTION 4

LIST OF FIGURES

SECTION 4

FORCE STRUCTURAL MAINTENANCE PLAN

In response to MIL-STD-1530A force management data package
(Task IV) specifications, aircraft contractors are required to
"prepare a force structural maintenance plan (FSMP) to identify
the inspection and modification requirements and the estimated
economic life of the airframe." The FSM requirements are a
natural product of the ASIP tasks performed on an airplane. These
analyses and tests reveal anticipated problem areas and accompany-
ing solutions or treatments. These requirements theoretically
are identified in sufficient detail to allow the OPR to establish
force budgetary planning, structural integrity planning, and
maintenance planning.

The force structural maintenance plan comprises a set of
structural maintenance actions and a schedule for performing these
actions in a rational sequence which is keyed to individual air-
craft usage. The initial FSM plan is based primarily on the air-
craft design service life, design usage spectra including
environmental effects, determination of safety-of-flight structure,
and defined inspection methods and capabilities. Results from
full-scale development test programs are also incorporated to
form the initial force structural maintenance plan. This initial
FSM plan is updated to reflect the baseline operational spectra
when it becomes available from the L/ESS program. Subsequent
updates may be made to the FSM plan for each significant change
in the operational spectra.

The FSMP fits into the overall concept according to
Figure 4-1. The original design analyses and test define the
limitations of the airframe relative to accomplishing the assumed
missions and life. The required inspections and maintenance
treatments are then tentatively programmed. The periodic results
of the IAT program furnish the structural manager the checkpoints
for executing the scheduled maintenance action. Concurrent with
this activity is the L/ESS program which updates mission usages

4-1
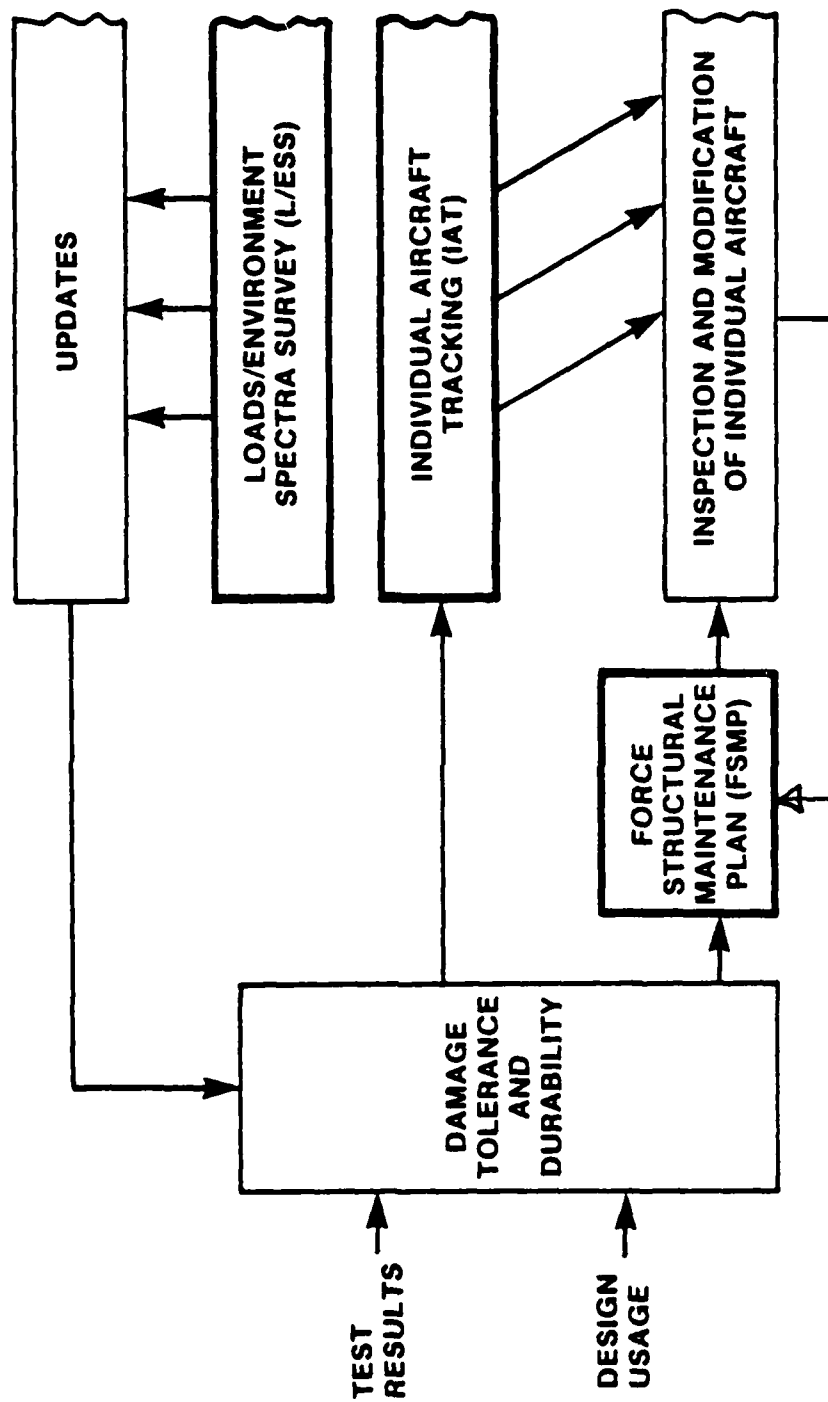
Figure 4-1. Schematic of the Role of the Force Structural Maintenance Plan.

and the impact of mission changes on the structural integrity of the airframe. New maintenance action schedules are then created to conform with the operational realities of the force and the FSMP is updated.

4.1 STRUCTURAL MAINTENANCE ACTION PLANNING

Structural maintenance can generally be classified as inspections, repairs, corrosion control, or modifications. Inspections are scheduled on the basis of a combination of analysis results obtained during the durability and damage tolerance analyses, test and service failure experience, and preventive maintenance on similar types of aircraft. Repair and corrosion control actions are triggered by specific inspection results. Modifications are scheduled as a result of service or test failure experience correlated with fleet and individual aircraft usage.

The initial FSMP is defined using applicable military standards; design philosophy and details (operating stress levels, material selection, etc.); analysis methodology; anticipated aircraft usage (mission mix, environmental effects, fuel management, force size, etc); reliability results (inspection uncertainty, structure accessibility, risk); compatibility with planned IAT and L/ESS methods; and program costs. During the full-scale development phase, maintenance procedures are formulated based on aircraft program requirements, determination of flight safety items, military specification, etc. Available structural data from static, fatigue, and flight test programs are added to form the design force structural maintenance plan. To remain current, the FSMP then requires accurate feedback from the operating commands regarding inspection results and the effectiveness of defined maintenance activities.

The FSMP requirements will vary between aircraft types. However, to provide the necessary information and instructions to execute a complete structural maintenance program, the FSMP should contain the following data:

a)   Specification of all anticipated inspection, repair and modification activity proposed for the airplanes. This information should be time phased by sequential airplane identities. Resource requirement estimates should be given for the long-range planning activity.

b)   A summary of the critical location and damage index values that key the required maintenance actions. The damage index values can be potential crack lengths (normalized or non-normalized) or an equivalent flight time measure (normalized or non-normalized).

c)   Supporting data required for a full explanation of procedures to be incorporated into the Air Force Technical Order System. (See paragraph 4.3).

The information of Item b is the core of the damage tolerance approach to structural integrity. Figure 4-2 presents an example of this data for an attack/fighter/trainer aircraft for which the damage index is a measure normalized equivalent flight hours. Figure 4-3 presents the same information in a display which emphasizes the scheduling of the inspection requirement.

The basis for determining the inspection intervals is a series of curves derived during the durability and damage tolerance assessment (DADTA) which estimate potential crack length as a function of time in the usage environment, Figure 4-4. For each critical location on the aircraft, the anticipated stress history is estimated and is used to predict the growth of a potential crack. The initial crack length, a_o, is representative of the longest crack that could be present at the critical point as the aircraft is placed into service. The first inspection time for the critical point is indicated at one-half the flight time required for the potential crack to grow to critical size, a_f. If a crack is found during the inspection, it is repaired and the initial crack length for the next interval depends on the quality of the repair. If a crack is not found, the initial crack length for the next interval is determined by the capabilities of the non-destructive evaluation (NDE) technique, a_{NDE}. Potential

Figure 4-2. Example of Operational Limit and Inspection Period Survey.

	Item	Economic Limit (Hrs) 0.005→0.03	Inspection Interval (Hrs) .05→a_{ip}/DI	Safety Limit (Hrs) .05→a_c/DI**	Special Considerations
1	MCS Skin at Inbd, Outbd. Pylon Post Aft (No. 3 and 7)	>8,000	1,100/ .28	2,200/.55	
2	Fuse Blkhd 480 Lug d=1.5 (No. 55)	>8,000	1,150/ .28	2,300/.58	Apls → 391
	d=1.75	>8,000	1,550/ .39, 4,000/1.00	3,100/.78, 8,000/2.00	Apls 392 & Sub ai = .022 (1)
3	MCS Wing Attach Rib Yw=24.6 (No. 14)	3,800	2,500/ .63	5,000/1.25	
	MCS Wing Boomerang Strap Yw=24.6 (No. 15)	>8,000	2,700/ .68	5,400/1.25	
4	MCS and OPW Fold Lug (No. 31/80)	>8,000	4,900/ 1.23, 2,800/ .70	9,800/2.45, 5,600/1.40	Lug Hole Lug Shank
5	MCS Skin at Rear Spar, Rear Spar Cap Yw 53.7 (No. 18)	8,000	3,050/ .76	6,100/1.53	
6	MCS BL-0 at R Spar (No. 10)	NR	4,150*/ 1.03	8,300/2.08	
	MCS BL-0 5th Spar (No. 9)	NR	4,800*/ 1.20	9,600/2.40	Strap Fail at 1,500 hrs.
7	MCS LWR Skin Y=32 (Item No. 1)	NR	6,100*/ 1.53	12,200/3.05	

NR - If safety limit >8,000 rework from economic limit not reqd.

* Requires wing removal

** Damage Index = $\dfrac{\text{Flt hrs Equivalent Baseline}}{4,000}$

Damage Index set to equal 1.00 @ 4,000 hours for convenience.

a_{ip} = flaw length @ inspection period

a_c = critical flaw length

(1) Subsequent to inspection

INSPECTION LEVEL:	ORGANIZATIONAL OR INTERMEDIATE	DEPOT LEVEL	ORGANIZATIONAL OR INTERMEDIATE	DEPOT LEVEL	ORGANIZATIONAL OR INTERMEDIATE	DEPOT LEVEL	ORGANIZATIONAL OR INTERMEDIATE
DAMAGE INDEX (3):	0.25	0.50	0.75	1.00	1.25	1.50	1.75
TIME (HOURS):	1,000	2,000	3,000	4,000	5,000	6,000	7,000
CRITICAL ITEM (2):							
PYLON	X	X	X	X	X	X	X
480 BHD		X (1)				X	
Yw = 24.6		X		X		X	
LUG SHANK			X			X	
LUG HOLE							
Yw = 53.7			X		X	X	
Yw = 32.2						X	
BL 0				X			

NOTES: (1) MODIFICATION OF 1.50 DIA LUB HOLE (AIRPLANES 1 THROUGH 391) IS REQUIRED. FOR AIRPLANES 392 AND SUBSEQUENT INSPECTION OF 1.75 DIA IS REQUIRED

(2) PYLON = WCS LOWER SKIN, INBOARD PYLON POST (ITEM 3 AND ITEM 7)
480 BHD = BULKHEAD STA 480, WING AFT ATTACH LUG, (ITEM 55) 1.50 DIA (AIRPLANES 1 THROUGH 391) AND 1.75 DIA HOLE (AIRPLANES 392 AND SUBSEQUENT)
24.6 = WCS LOWER SKIN, WING ATTACH LUG, Yw - 24.6 (ITEM 14 AND ITEM 15)
LUG SHANK = WCS, WOP FOLD LUG Yw - 135.2 (ITEM 31/40) LUG SHANK
LUG HOLE = WCS, WOP FOLD LUG Yw - 135.7 (ITEM 31/40) LUG HOLE
Yw - 53.7 = WCS LOWER SKIN, REAR SPAR AND REAR SPAR CAP (ITEM 18)
Yw - 32.2 = WCS LOWER SKIN, 5TH SPAR Yw - 32.0 (ITEM 1)
BL 0 = WCS LOWER SKIN, CENTER SPLICE, REAR SPAR (ITEM 10): WCS LOWER SKIN 5TH SPAR SPLICE (ITEM 9)

(3) DAMAGE INDEX = TIME (HOURS) EQUIVALENT BASELINE / 4,000

Figure 4-3. Example of Recommended Inspection/Modification Intervals for Critical Items.
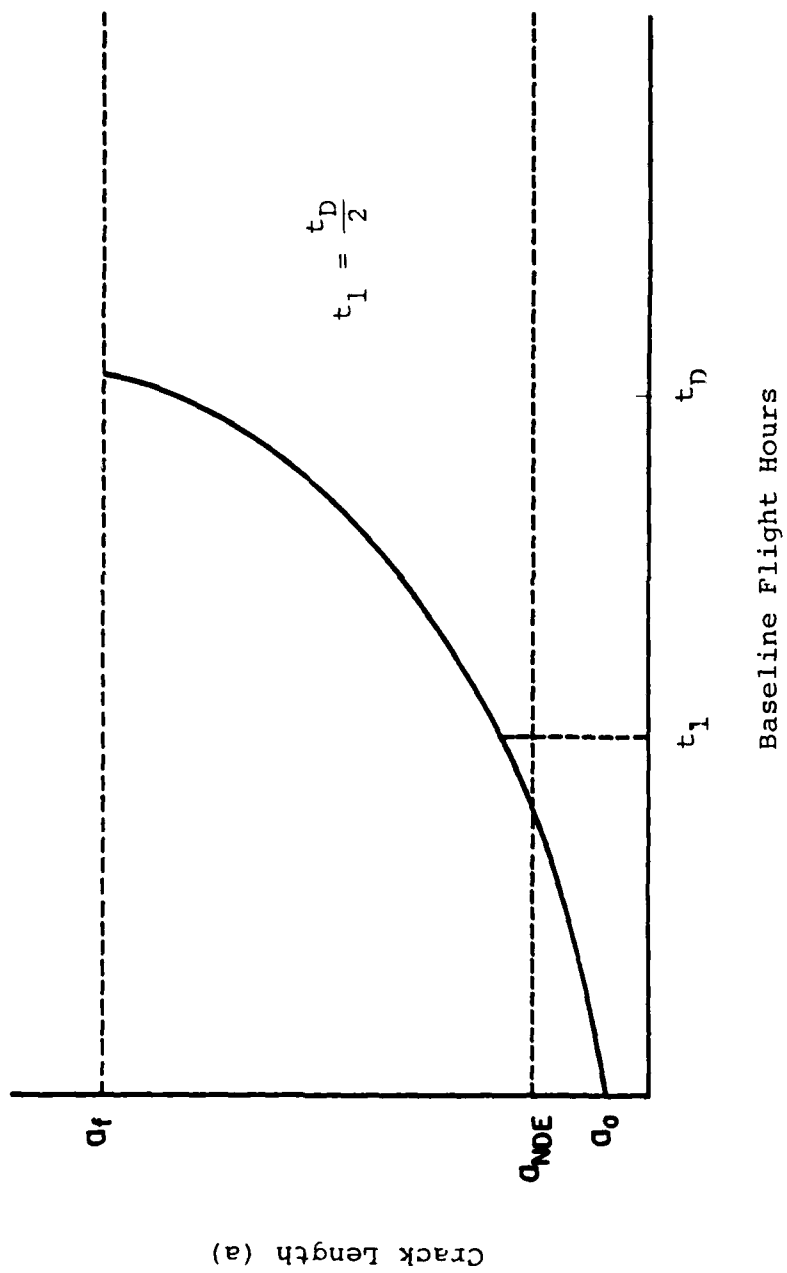
Figure 4-4. Crack Growth Life Curve for First Inspection.

4-7

crack growth during the next interval is then computed and the recurring inspections are scheduled at one-half the flight time required for a potential crack of length a_{NDE} to grow to critical, Figure 4-5. The process is repeated as often as necessary throughout the life of the structure.

The above inspection policy is designed to eliminate catastrophic failures through the detection of cracks at known critical locations. If cracks develop at unexpected locations, the FSMP will require updating. Since the timing of the inspections is based on the growth of cracks which are longer than those expected to be in the structure, the early inspections will find few cracks. This could result in a motivational problem among the maintenance personnel. If the critical crack size is small in comparison to the capabilities of the NDE system, it is also possible to perform a required inspection and to reset the initial crack length, a_{NDE}, at a size larger than that predicted before the inspection. This anomaly is due to the requirement for scheduling inspections at half the time to critical crack length. This requirement is considered necessary to permit a second chance at finding a large crack before it becomes critical (NDE systems are not infallible).

Experience with the maintenance of existing aircraft has shown that structural problems are relatively minor in comparison to other major aircraft systems. These other systems will tend to drive the scheduling of maintenance activities as they will receive higher priorities. The FSMP should recognize this fact and make allowances for the possibility of subordinating the structural inspection schedule to that of other systems. A risk analysis should be performed to demonstrate any trade-offs that might result from the subordinated schedule.

4.2 FSM BY INDIVIDUAL AIRCRAFT OR COMPONENT

The FSM plan defines the schedule for structural maintenance type actions, i.e. inspections, modifications, and retirement, through the use of crack growth curves in the durability and damage tolerance assessment (DADTA). These crack growth curves are derived for specific locations in the structure where crack growth damage, if allowed to become critical, could impair the
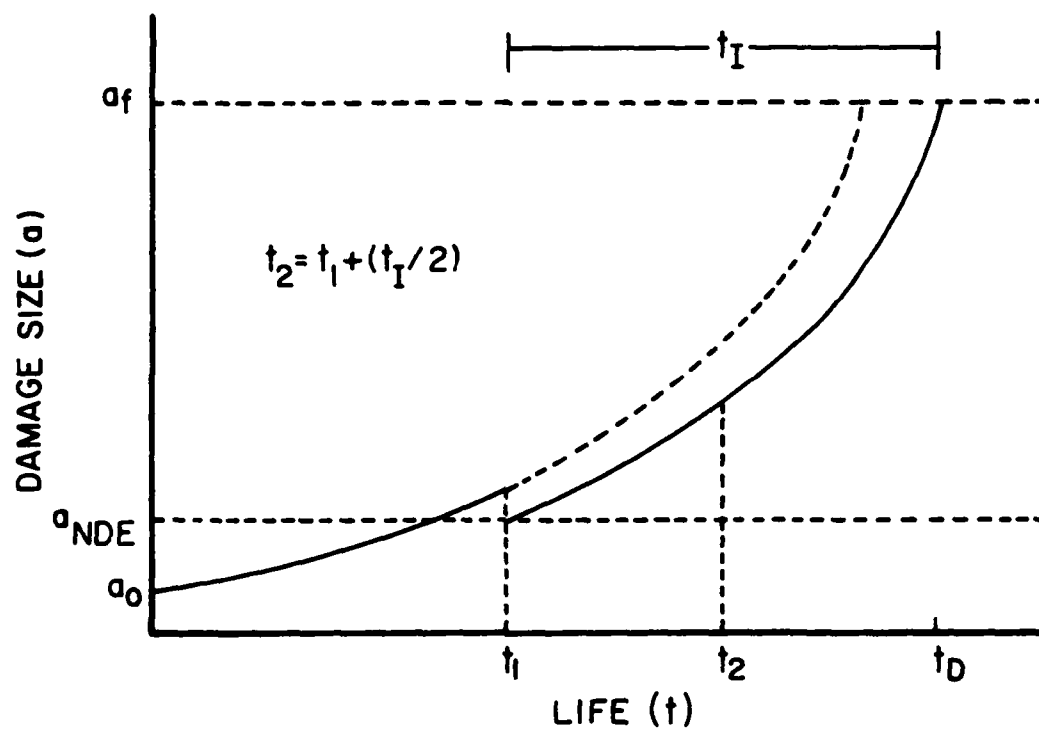
Figure 4-5. Crack Growth-Life Curve at Second Inspection.

safety of the aircraft, Figure 4-4. One basic feature of the
set of FSM plan crack growth curves is that the curves are derived
assuming a planned mission usage. Planned crack growth curves
are based on predicted future usage stress spectra and represent
the best estimates of rates of future crack growth. Since
individual aircraft will not be subjected to the average stress
environment, individual aircraft tracking (IAT) is introduced
to account for differences between average and actual stress
environment.

A direct comparison between the damages that accrue due to
individual aircraft usage is achieved by referencing individual
aircraft crack length to the FSM plan crack growth curves for
each control point. An example will outline the manner in which
the FSM plan's crack growth life curve is used in conjunction with
that of the individual aircraft. Figure 4-6 provides the two
curves and shows how the current damage in the individual aircraft
relates the individual aircraft's usage $(t_{A/C})$ to that of the FSM
planned usage (t). The curve in Figure 4-6(a) represents crack
growth up until the current quarter of usage for an individual
aircraft. The individual aircraft usage $(t_{A/C})$ is measured in
the same units, e.g. flight hours, as were used to represent the
usage for the FSM plan's crack growth curve. Note that the
ordinate for the curves in Figures 4-6(a) and 4-6(b) are identical
with respect to the limits of damage and that the shapes of
individual aircraft curve and the FSM plan curve are somewhat
similar. These conditions provide the basis for deriving general
methods for comparing individual aircraft and for referencing
them to some standard.

As illustrated in Figure 4-6, the current crack length in the
individual aircraft defines an equivalent service life used in
terms of the FSM plan's defined usage. This level of service
life is then used to establish the remaining life for the
individual aircraft at the specified control point

$$t_L = t^* - t \qquad (4-1)$$

4-10
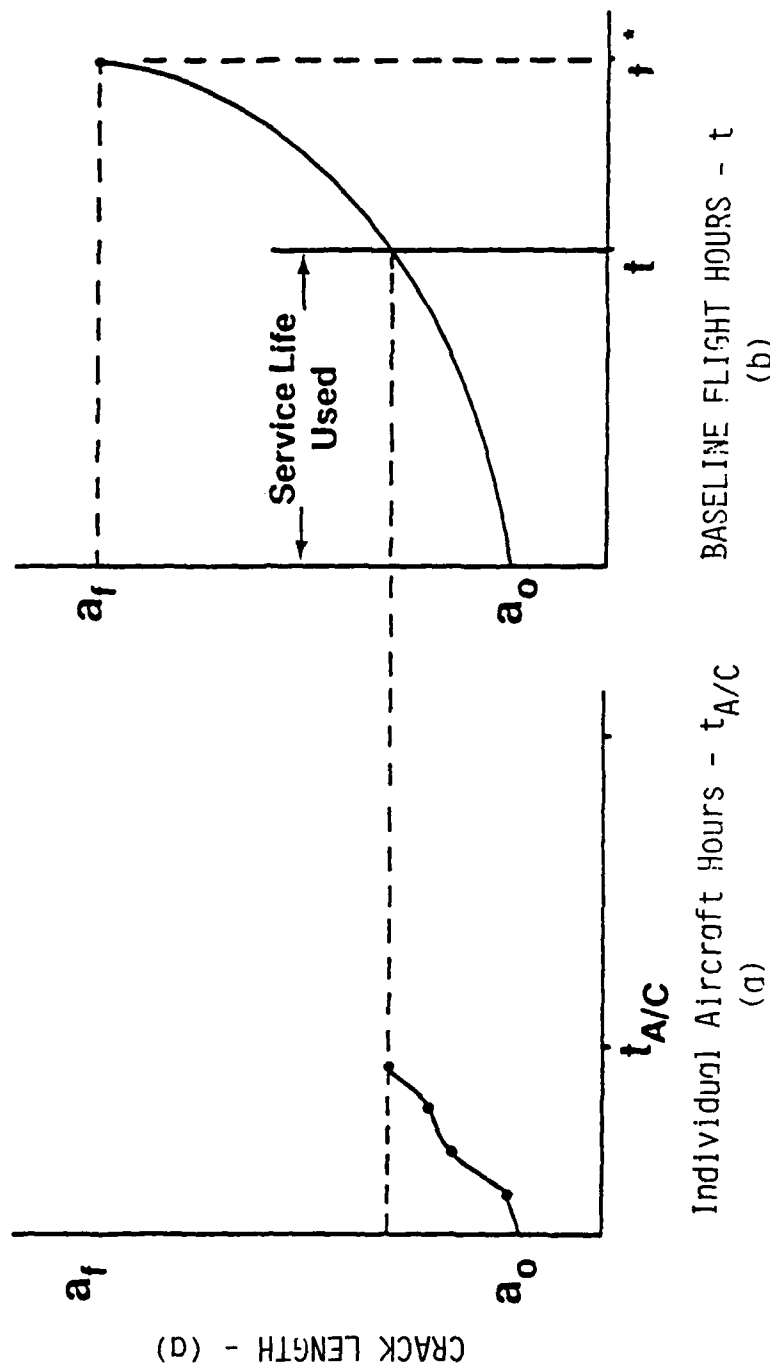
Figure 4-6. Relating Individual Aircraft Usage to FSM Plan Usage
for Specified Critical Point.

Remaining life is defined as flight hours to a maintenance action or to aircraft retirement. The projected calendar time (L) associated with the aircraft reaching the crack length limit (a_f) is obtained by dividing the remaining service life by the planned monthly utilization rate (U_p, which is described in terms of the FSM plan's defined usage), i.e.

$$L = \frac{t_L}{U_p} \qquad (4-2)$$

The projected calendar date (D_p in years and months) for reaching a critical level of damage would then be obtained by adding the calendar time to the current date (D_c)

$$D_p = D_c + L \qquad (4-3)$$

The above example of structural maintenance scheduling is stated in terms of crack growth which results from the planned usage severity. In tracking attack/fighter/trainer aircraft, a damage index has been introduced which correlates the current estimate of crack length at a control point with a normalized time to crack length limit in the planned usage environment. In this approach, tracking data are expressed in terms of the damage index rather than potential crack length. The correlating crack growth-life curves and denormalizing factors are available in the FSMP. Effects of differences in planned usage severities are modeled by scaling the damage index to a different base. For example, the planned or baseline usage would call for a maintenance action when the damage index reaches unity. A particular base may have a less severe stress environment and this could be reflected by requiring the damage index to reach a higher value as the indicator of the maintenance action. The same result can be achieved by different denormalizing factors when estimating the time to main- tenance actions. Both of these scaling approaches can be modeled in estimating time to maintenance action by the formula

$$L = \frac{t_L}{U_p} \cdot S \qquad (4.4)$$

4-12

where S is a severity factor which reflects planned usage at a particular base with the baseline usage upon which the FSMP was constructed. Note that the use of this simple scaling is based on the assumption that changes in usage severity can be modeled by a linear change in the time to reach the crack length limit.

The above formulas for estimating the calendar time until a maintenance action are based on parameters which will not be known exactly at the time of the projection. The current baseline age is dependent on the accuracy of tracking system and the shape of the crack growth-life curve. Planned flying rates are influenced by many factors and their degree of scatter depends on the particular aircraft model. Similarly, projected usage severities are also known in only a statistical sense. As a part of the FSMP, the effects of the variation of these statistical quantities on the risks and costs of mistimed maintenance actions should be evaluated.

Tracking data can be used to impact the scheduling of structural maintenance actions for entire aircraft or major components of aircraft. The method is based, however, on maintaining extensive records for the control points and feedback is required from the maintenance system so that potential crack length values can be reset. For component tracking, the feedback must also contain sufficient data to locate the components on the correct aircraft.

4.3 FSM IMPLEMENTATION

ASIP force structural maintenance operations are implemented through the Air Force Technical Order (T.O.) system as defined by T.O. 00-5-1, Figure 4-7. Drafts of these documents are usually developed by the contractor as part of the initial aircraft procurement contract requirements and supplied to the user as the aircraft becomes operational. The purpose of the technical order system is to provide a set of reference manuals which specify methods and requirements for recurring and non-recurring maintenance functions.

AIR FORCE TECHNICAL ORDER SYSTEM

TECHNICAL MANUALS

METHODS & PROCEDURES TECHNICAL ORDERS

ABBREIVATED TECHNICAL ORDERS

INDEX TYPE TECHNICAL ORDERS

TIME COMPLIANCE TECHNICAL ORDER

ABBREIVATED TECHNICAL ORDERS:
- INSPECTION WORK CARDS SEQUENCE CHARTS AND WORKSHEETS
- LUBRICATION CHARTS
- CHECK LISTS
- JOB GUIDE MANUALS

INDEX TYPE TECHNICAL ORDERS — NUMERICAL INDEX & REQUIREMENT TABLE:
- ALPHABETICAL
- CROSS REF. TABLES
- LIST OF APPLICABLE PUBLICATIONS

METHODS & PROCEDURES TECHNICAL ORDERS:
- AF TECHNICAL ORDER SYS.
- DISTRIBUTION & STORAGE OF AF TECHNICAL ORDER SYSTEM PUBLICATIONS
- VISUAL INSPECTION SYS.
- HI-VALU ITEM LISTS
- (OTHER)

TECHNICAL MANUALS:
- AIRCRAFT
- MISSILES
- CEM
- SPECIAL WEAPONS
- OTHER EQUIPMENT
- COMMERCIAL TYPE PUBLICATIONS

TIME COMPLIANCE TECHNICAL ORDER:
- IMMEDIATE ACTION
- URGENT ACTION
- ROUTINE ACTION
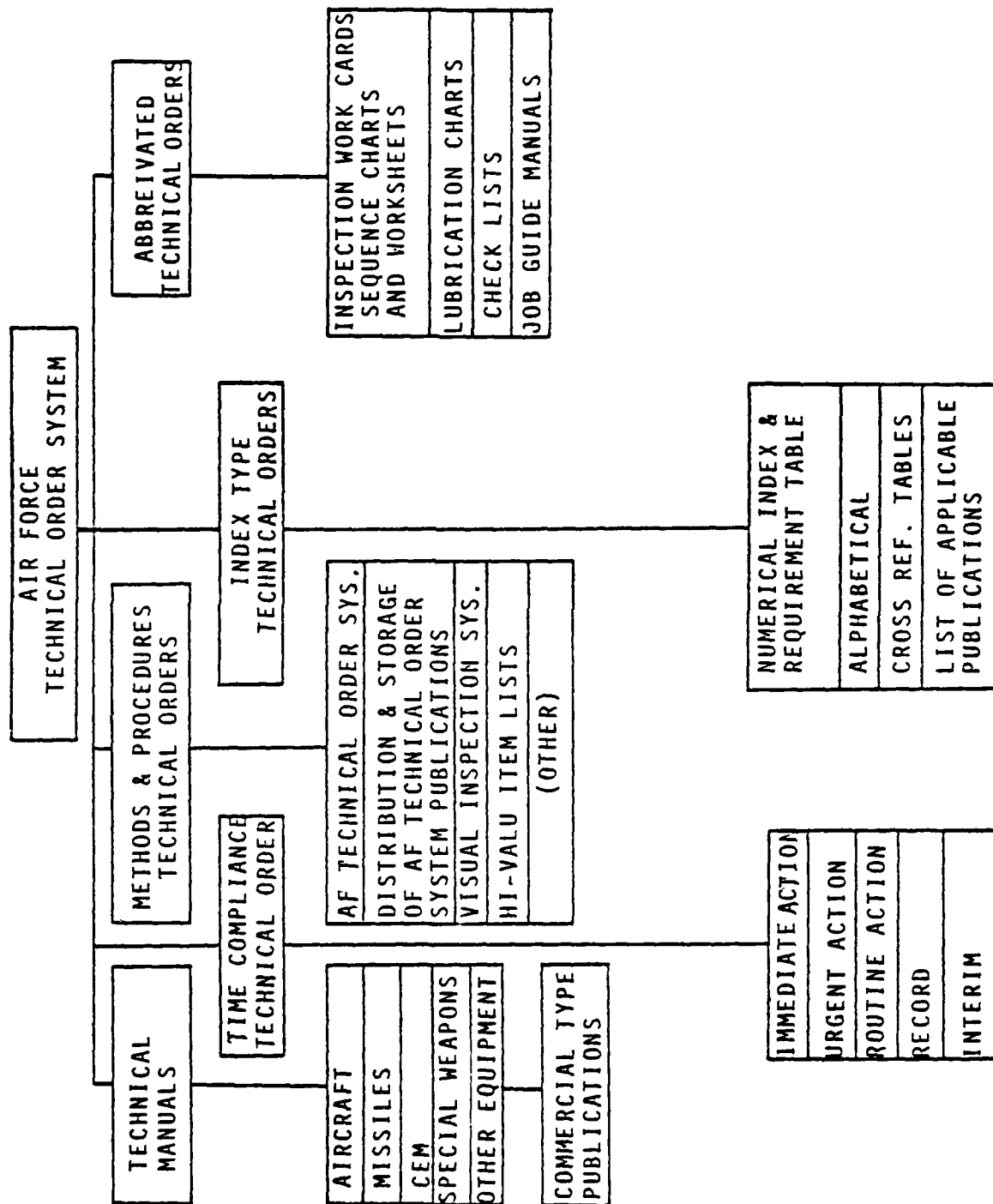- RECORD
- INTERIM

Figure 4-7. Types of Technical Order Publications (Ref. T.O. 00-5-1).

The primary documents applicable to ASIP activities are:

- Structural Repair Instructions (T.O.-3)
- Aircraft Scheduled Inspection and Maintenance Requirements (T.O.-6)
- Maintenance Work Unit Codes (T.O.-06)
- Aircraft Corrosion Control (T.O.-23)
- Nondestructive Inspection Procedures (T.O.-36)
- Time-Compliance Technical Orders (T.C. T.O.'s)

(NOTE: The T.O. numbers in parenthesis are standard for that document throughout the Air Force inventory. The remaining nomenclature is derived from the standard Model/Design/Series (MDS) format; e.g., 1C-5A-36, 1B-52D-3, 1T-43A-23, etc). Each of these technical orders is discussed in detail in the following paragraphs.

4.3.1 Structural Repair Manual (T.O.-3)

Since no test or in-service experience exists during the aircraft design phase, the initial structural repairs are generalized concepts designed to repair "typical" cracks in major structure such as skins, spar webs and caps, fuselage frames and stringers. Guidelines for materials selection, repair size, fastener attachments and finishing processes are included, along with installation procedures. As structural development test results become available, specific potential problem areas are identified, and corresponding repairs are designed to "equivalent strength" criteria. Thus, the static strength capability of the repair configuration is equal to or greater than the original structure. In addition to the repair designs, general information regarding such items as aerodynamic smoothness requirements, aircraft jacking instructions, control surface balancing, general ship practices, etc. is also included.

An important part of the T.O.-3 is the classification of damage and types of repair. Damage items are separated into three major categories: negligible, repairable and damage necessitating replacement of parts. Repairs are classified as either field level or depot level, depending on the complexity of

the task and available materials and facilities. No attempt is made in the T.O.-3 manual to classify the defined repairs due to the variability of these factors. However, emphasis is placed on simplicity of design in order to minimize costly depot level repairs.

4.3.2   Scheduled Maintenance Requirements (T.O.-6)

The T.O.-6 defines "complete requirements for accomplishing scheduled maintenance on the aircraft during its entire service life." This is done by initially establishing a schedule of recurring maintenance time intervals, and then defining inspection packages for each interval based on a predetermined rationale agreed upon by the Air Force and the contractor. Initial candidate locations are determined primarily by considering safety-of-flight items, such as skins, spars, frames, etc. Analyses of these areas are performed to determine the inspections required to assure continued structural integrity. In addition, fatigue sensitive areas such as skin cutouts are identified, usually based on past experience on other aircraft or empirical analysis. As in the case of the T.O.-3, development test program results are used to further define inspection items and intervals. Other types of maintenance-related data are included in the T.O.-6, such as component replacement schedules, base level repair restrictions and historical document requirements.

In addition to the Programmed Depot Maintenance (PDM) inspections, most current aircraft have depot-level Controlled Interval Extension (CIE) and Analytical Condition Inspection (ACI) requirements as defined in T.O. 00-25-4 and specified in the T.O.-6 manual. The purpose of the CIE program is to "provide technical data to determine the feasibility of changing PDM intervals and/or work requirements." In this program, a selected number of air-craft are scheduled for PDM inspection at longer-than-normal inter-vals, with regular base level isochronal maintenance being performed as required. Results of the subsequent PDM inspections (a portion of the CIE sample aircraft also receive ACI's at this time) are then used to retain or modify present PDM intervals. ACI require-

ments consist of in-depth inspections which are performed on a representative sample of PDM aircraft each year per T.O. 00-25-4. This program is used to "generate data for engineering and technical evaluation of the relative MDS aircraft condition resulting from corrosion, overstress, wear, and other effects caused by aircraft age, operational usage and environmental exposure." The overall intent of the CIE and ACI programs is to reduce depot level maintenance requirements without sacrificing aircraft safety and a substantial reduction in costs and downtime may be realized by the efficient application of these programs.

4.3.3 Work Unit Code Manual (T.O.-06)

In conjunction with the T.O.-6 manual, a maintenance work unit code document (T.O.-06) is issued. The function of this manual is to code maintenance information in a manner which can be converted into computer language. This code conversion system, standard throughout the Air Force, allows mechanical compilation and storage of the data to be performed as a part of the AFM 66-1 maintenance data recording system. The codes are used to document information such as type, location and severity of defects, when discovered and action taken.

4.3.4 Aircraft Corrosion Control (T.O.-23)

In general, the T.O.-23 manual is an "after-the-fact" document which utilizes service experience to identify corrosion susceptible areas and treatment procedures. Although attempts are made to minimize this problem through the use of optimum detail design, materials selection and surface finish criteria, environmental and usage variabilities preclude its elimination. Thus, accurate feedback from actual force usage is necessary to define adequate corrosion control measures and to provide guidelines for elimination of corrosion in subsequent aircraft modifications. Corrosion related maintenance activities such as interior/exterior cleaning procedures and microbal infestation control are also described in the T.O.-23 manual.

4.3.5   Nondestructive Inspection Procedures (T.O.-36)

This document is an outgrowth of the T.O.-6 Inspection manual, and it contains detailed instructions for performing inspections which are not damaging to the structure. Procedures for all T.O.-6 requirements (except most visual inspections) are described in the T.O.-36 manual; therefore, its content is determined primarily by the T.O.-6 items. It is important to note that the T.O.-36 is strictly a "how-to" technical order; its use is triggered by a specified callout in the T.O.-6 manual. In some cases, NDI procedures are defined (usually based on preliminary test or analysis results) for a location where no current inspection requirement exists. These inspections are sometimes performed as a part of normal depot level maintenance activities (PDM, ACI, etc.) at the discretion of the ASIP manager. If cracks are found, a recurring inspection requirement for this location will then be added to the T.O.-6 manual.

NDI procedures provide inspection instructions and illustrations in sufficient detail so that trained NDI technicians can efficiently carry them out. These procedures are developed in accordance with MIL-M-38780, which describes the required content and format for NDI procedures, and are contained in Air Force Tech Orders Nondestructive Inspection Manual. A variety of information is included in the NDI procedures. A description of the area of the aircraft is provided and includes such items as materials of construction, alloys and surface finishes. The type and general location of potential flaws are described, the type NDI technique to be used is specified along with the NDI equipment and standards required, any special factors associated with access to the area to be inspected are specified, and any special preparation of the area to be inspected are described. Special instructions for calibrating the inspection equipment are given and then step-by-step instructions for conducting the inspection are provided, along with any required illustrations. Instructions are also provided for reporting of the inspection results. Normally, a back-up NDI procedure is specified, primarily for use in verifying defect indications.

The standard Nondestructive Inspection (NDI) techniques utilized throughout the Air Force are Eddy Current (surface probe and bolt hole probe), Ultrasonic, Penetrant, Radiography, and Magnetic Particle. The application frequency of the individual techniques at the various Air Force bases and Air Logistics Centers varies widely, depending on the local inspection requirements. Flaw detection reliability also varies widely due to flaw size, NDI technician, inspection techniques, structure configuration, and many other factors.

Eddy current inspection is effective for the detection of surface or near surface cracks in most nonferrous aircraft parts. The method can be applied to airframe parts or assemblies where the inspection area is accessible for contact by the eddy current probe. An important use of eddy current inspection on aircraft is for the detection of cracking caused by fatigue or stress corrosion around fastener holes; however, cracks propagating from fastener holes can be detected by this method only after they extend beyond the fastener head. Special bolt hole probes are available and are used (with the fastener removed) for locating cracks emanating from the wall of the fastener hole. Inspection is accomplished by inducing eddy currents into the part and observing electrical variations in the induced field. The character of the observed field change is interpreted to determine the nature of the defect. A sharp eddy current instrument meter deflection observed as the eddy current probe is moved over the inspection areas will indicate a probable crack in the part.

Ultrasonic inspection uses high-frequency sound waves as a probing medium to provide information as to the state of various materials. This method is effective for the inspection of most metals for surface and sub-surface defects. The method requires that at least one surface of the part be accessible for transducer contact in the vicinity of the area to be examined. The inspection is accomplished by inducing the ultrasound into the part by a contacting transducer and picking up reflections of this sound from within the part. The detected ultrasonic reflections are electronically displayed on an oscilloscope and interpreted for indications of defects.

The fluorescent penetrant method of inspection requires that the inspection surface be free of surface coating and be thoroughly cleaned. After cleaning, penetrant is applied to the surface to be inspected. After remaining on the surface for a prescribed period of time, it is then cleaned from this surface using a solvent cleaner. A developer is then applied and flaws are detected under black light as the fluorescent penetrant bleeds out of the flaw onto the surface.

X-ray inspection is used to show internal and external structural details of all types of parts and material. This method is used for the inspection of airframe structure for defects otherwise inaccessible for other methods of nondestructive inspection, or to verify conditions indicated by another method. Inspection is accomplished by passing the X-ray beam through the part or assembly to expose a radiographic film. The processed film shows the structural details of the part by variations in film density. The radiograph is interpreted for indications of defects.

Magnetic particle inspection is effective in the detection of surface and near surface defects in ferromagnetic parts. The method may be applied to installed or disassembled parts. The inspection is accomplished by inducing a magnetic field in the part, and applying a liquid suspension of iron particles or dry magnetic powder to the surface to be inspected. Defects in the part cause local bipolar perturbations in the magnetic field which attract the magnetic particles, producing visible indications by color contrast or by fluorescence under "black light." This method requires that the surface under inspection be thoroughly clean.

4.3.6 Time Compliance Technical Orders (T.C.T.O's)

Since the technical order system has been established as the official mechanism for defining structural maintenance requirements and procedures, updates to the existing FSM plan are implemented either by revising the applicable T.O. documents or by issuing Time Compliance Technical Orders (TCTO's). The TCTO system

as authorized by AFR 8-2 and described by T.O. 00-5-15, provides instructions for accomplishing and/or recording "one time" maintenance operations to aircraft systems, such as inspections, repairs, retrofits, etc. Overall TCTO systems management is the responsibility of AFLC, although the aircraft system manager (AFSC or AFLC) at the time of TCTO approval is responsible for its technical content and adequacy. As the title infers, the requirements of a particular TCTO are to be completed within time limits specified in that TCTO. It is emphasized that the TCTO system is used for "one time" FSM operations; recurring maintenance activities are modified by revisions to the basic T.O. manuals.

4.3.7 Reliability Centered Maintenance Program

A recent change in the inspection program for some USAF Transport/Bomber aircraft has been the incorporation of the Reliability-Centered Maintenance zonal inspection philosophy into Air Force aircraft maintenance. This program is based on the "Airline/Manufacturer Maintenance Program Planning Document," prepared by the Maintenance Steering Group (MSG) of the Air Transport Association in 1970. This document, commonly referred to as MSG-2, defines a logical procedure for developing an efficient scheduled maintenance program in order to "prevent deterioration of the inherent design levels of reliability and operating safety of the aircraft, and to accomplish this protection at the minimum practical costs."

Inspections of primary structure as determined through structural analyses or tests are specified at the required intervals and are conducted by structural inspectors using the appropriate NDI techniques. Zonal inspection of certain areas of the aircraft for hydraulic, electrical, structural, or other discrepancies by one inspector is also performed, with follow-up by a specialist if a discrepancy is noted. The previous method required all areas to be inspected by one specialist for hydraulic problems, another for electrical items, a third for structural integrity, etc. Also, implementation of the zonal inspection program is preceded by a complete review of the existing inspection requirements in the light of test and service experience, criticality, and the

4-21

likelihood of discrepancies being found during other flights or ground operations. Special inspections of the specific locations are included as necessary.

Implementation of the zonal inspection program is considered to be a current FSM technique. However, it is noted that the definition of inspection requirements continues to be based on 'average' utilization for the entire Force of aircraft and does not recognize, as yet, the IAT program philosophy in which individual aircraft usage severity, crack growth, and NDI are all combined to provide a more sensitive device for scheduling periodic inspections. The present system assumes that all aircraft are inspected in the same manner at the same calendar or flight hour interval, except for special inspection requirements. Thus, the special inspection requirements section in T.O.-6 appears to be the present vehicle for accomplishing individualized inspections of aircraft, and it is not considered that it was intended for this purpose.

4.3.8 Structural Maintenance Action Scheduling

In practice, structural maintenance actions will be scheduled on the basis of individual aircraft tracking output as discussed in Paragraph 4.3.2 or on the basis of flight hours or calendar time. For a particular aircraft, the T.O.-6 might specify a periodic Programmed Depot Maintenance (PDM) or Analytical Condition Inspection at equal calendar time increments. The output of the individual aircraft tracking program should then be capable of establishing a priority system for scheduling individual aircraft into the Depot. Further, special inspections should be added to particular PDM or ACI actions on the basis of potential crack length at critical locations.

It is necessary that the output of the individual aircraft tracking system be designed to provide the data in a convenient format for making scheduling decisions. Examples of such data are provided in Paragraph 5.1.

4.3.9 Structural Maintenance Action Reporting

The scheduling of maintenance actions on the basis of potential crack length is highly dependent on good feedback regarding the results of inspections and maintenance actions. The mechanism for maintenance data collection and feedback is the AFM66-1 system. However, because of the extensive use of coded information and the generalization necessary to handle all aircraft subsystems, the structural maintenance data collected under the AFM66-1 system is generally not adequate for making changes to the force structural maintenance plan. Some aircraft systems have attempted to get a more meaningful output from the AFM66-1 system by providing specific work unit code numbers in the T.O.-06 which are assigned to a particular type of defect at a particular structural location.

Figure 4-8 is an example of an alternate approach where specific structural inspection findings are collected on the same form as the individual aircraft tracking data. TCTO's for the special inspections can be worded to require feedback of results and time of modification. This feedback (to the ASIP Program Manager) must then be assimilated into the IAT program manually or through a supplemental computer program.

Figure 4-9 illustrates another alternate method of obtaining inspection data. Specific data on crack locations and size can be obtained. Inspections of areas with no cracks found are also documented by this form. The form can be read by optical mark sensing equipment for input to the IAT or FSM computed program.

Finally, a reliable and informative source of service structure defect data is the airframe manufacturer's records collected by field representatives. These individuals are dedicated to ensure trouble-free fleet operation and are generally trained to spot defects which might lead to structural integrity problems. They tend to react more rapidly to a repeated problem and gather relatively detailed information.

4-23

A-37B AIRCRAFT FATIGUE TRACKING RECORD

AIRCRAFT SERIAL NUMBER: 68 0079 27
MONTH: 10 YEAR: 77
BASE: 15

TOTAL AIRFRAME HOURS PRIOR TO FIRST FLIGHT OF MONTH: 2607.9

MISSION DATA SUMMARY

STORES CONF	MISSION CODE	LDG	FLIGHT TIME	I/C
10 4	1 9	01	1.9	1
10 4	1 9	01	1.5	1
4 1	1 4	34	3.0	1
4 1	1	01	1.2	1

SPECIAL INSPECTION REPORTING

LOCATION/DESCRIPTION	DATE C/B	AIRFRAME HOURS	TYPE PROBE	RESULTS
BUTT LINE 26.0 UPPER FORWARD CARRY THRU			☐ HAND HELD ☐ MOTORIZED	☐ NEGATIVE ☐ CRACK
BUTT LINE 27.0 FORWARD UPPER CARRY THRU			☐ HAND HELD ☐ MOTORIZED	☐ NEGATIVE ☐ CRACK
BUTT LINE 30.0 & 33.1 FORWARD LOWER CARRY THRU			☐ HAND HELD ☐ MOTORIZED	☐ NEGATIVE ☐ CRACK
BUTT LINE 36.0 CANOPY RAIL ATCH PTS			☐ HAND HELD ☐ MOTORIZED	☐ NEGATIVE ☐ CRACK
WING STATION 48.0 LOWER CENTER LUG			☐ HAND HELD ☐ MOTORIZED	☐ NEGATIVE ☐ CRACK
WING STATION 51.0 FRONT SPAR UPPER CAP			☐ HAND HELD ☐ MOTORIZED	☐ NEGATIVE ☐ CRACK

REMARKS

AFTO 227. 12

Figure 4-8. A-37 Aircraft Fatigue Tracking Record.

Figure 4-9. Automated Inspection Tracking System Form.

A comprehensive NDI inspection results feedback system is vitally needed to work in conjunction with the crack growth based IAT programs. The safe-use interval of flying based on NDI and crack growth analytics will be severely restricted in usefulness without a working and maintained feedback system.

4.4 FSM UPDATE

An effective FSM plan must have the capability to respond to changes in force utilization which affect scheduled maintenance operations. Assuming this capability exists, emphasis is placed on obtaining pertinent structural information for use in planning future FSM activities. Typical sources of information are structural tests, durability and damage tolerance analyses, and force usage experience.

Due to their complexity, many test programs such as full-scale fatigue tests are not completed until after the aircraft has entered into service. These programs identify additional fatigue-critical locations omitted from the initial FSM plan, provide a means for testing repair or retrofit configurations, and verify/alter existing maintenance intervals based on test-service correlations.

Operational usage data from the L/ESS and IAT programs are used to evaluate and update if necessary, assumptions regarding flight loads and environment, aircraft frequency response, stress transfer, and mission profiles. These data, together with information from the test programs are used to re-evaluate the structure through a durability and damage tolerance assessment. Predicted crack growth-life curves using the new input are generated for all critical locations and the curves are used to identify or modify the planned maintenance actions. This update is repeated for significant changes in usage or aircraft configuration.

Finally, force usage feedback from field level and depot level maintenance programs (also commercial and foreign operators, if applicable) is the most important source of information concern-

ing the effectiveness of existing FSM plans. Inspection results are used to determine the adequacy of defined inspection locations, methods, and intervals.

Since the technical order system has been established as the official mechanism for defining structural maintenance requirements and procedures, updates to the existing FSM plan are implemented either by revising the applicable T.O. documents or by issuing Time Compliance Technical Orders (TCTO's). The TCTO system, as authorized by AFR 8-2 and described ty T.O. 00-5-15, provides instructions for accomplishing and/or recording "one time" maintenance operations to aircraft systems, such as inspections, repairs, retrofits, etc. Overall TCTO systems management is the responsibility of AFLC, although the aircraft system manager (AFSC or AFLC) at the time of TCTO approval is responsible for its technical content and adequacy. As the title infers, the requirements of a particular TCTO are to be completed within time limits specified in that TCTO. It is emphasized that the TCTO system is used for "one time" FSM operations; recurring maintenance activities are modified by revisions to the basic T.O. manuals.

4.5 ECONOMIC LIFE ESTIMATION

MIL-STD-1530A requires an estimate of the economic life of the airframe to be included as part of the FSM plan. Economic life is defined as "that operational life indicated by the results of the test program." Further, "economic life of the test article has been attained with the occurrence of widespread damage which is uneconomical to repair, and, if not repaired, could cause functional problems affecting operational readiness. This can generally be characterized by a rapid increase in the number of damage locations or repair costs as a function of cyclic test time." Economic life indicators are best derived from the actual cracking experience of the full-scale fatigue test articles. Analytic correlation with these test cracks can relate the test loading history and service aircraft load spectra with crack growth analysis. The correlation analysis can then be used to provide estimates

and indicators as to when widespread cracking might be anticipated. This analysis requires an input of estimated initial quality which can be related to crack initiation and growth. Reference 8 recommends characterizing initial quality in terms of equivalent initial flaw size distributions. Economic life can then be estimated as the time required for, say, the average equivalent initial crack to grow to critical length.

SECTION 5

INDIVIDUAL AIRCRAFT TRACKING

SECTION 5
TABLE OF CONTENTS

5.0.1

SECTION 5

TABLE OF CONTENTS (Cont.)

SECTION 5
LIST OF FIGURES

SECTION 5
LIST OF FIGURES (Cont.)

SECTION 5
LIST OF TABLES

SECTION 5

INDIVIDUAL AIRCRAFT TRACKING

MIL-STD-1530A states that "the objective of the individual aircraft tracking program shall be to predict the potential flaw growth in critical areas of each airframe that is keyed to damage growth limits of MIL-A-83444, inspection times, and economic repair times." To accomplish this objective, individual aircraft tracking comprises the selection of usage parameters suited to life estimation, a data collection technique, and a data reduction and analysis scheme. This section addresses the subject by presenting (1) a review of the tracking requirements; (2) a discussion of tracking methods as determined by primary data source; (3) a comparison of the techniques; and (4) a discussion on IAT system implementation.

5.1 USAGE TRACKING REQUIREMENTS

The requirement of the IAT System can be defined by a specification of the desired IAT output. Task V of MIL-STD-1530A assigns to the Air Force the responsibility "for deriving individual maintenance (inspection and repair) times for each critical area of each airplane by use of the tracking analysis methods and the individual airplane tracking data." The fulfillment of this responsibility while meeting the above stated objective of the IAT function will require as a minimum,

    a) periodic estimates of potential crack lengths at the critical points of each airplane from the IAT output;

    b) a crack growth-life curve for anticipated usage from the FSM Plan; and

    c) estimates of future flying rates and flying severity from the operating commands.

Thus, the minimum output of the IAT system would be a listing by tail number of the current potential crack lengths at the critical points. To use these data, however, would require a later merging with the other sources to obtain the predicted times to maintenance.

Therefore, the output of the IAT system is usually considered to also contain combined output of the predicted times to maintenance actions.

The available data required of a tracking system will vary greatly depending first on the class of aircraft (transport/bomber or attack/fighter/trainer) and, second, on the choice of analysis methods in defining the system. The IAT output can and should be defined to take advantage of any data that provides useful lists, tables, or figures for making force management decisions. Such data products can be easily obtained as a part of the force management data package if they are specified as desired output during the planning stages.

The following paragraphs describe usage tracking requirements by presenting examples of types of IAT output. Since different aircraft classes have different data requirements and the varieties of data presentation formats are endless and a matter of personal preference, the examples represent only a few of the possibilities for presenting and summarizing force management data.

5.1.1 Current Status Reports

At the time of each IAT update, output is generated which is descriptive of the current structural status of the force. The current status is based on estimates of potential crack length (or, equivalently, on damage indices or baseline hours) and a list of these values for each airplane is generally considered to be a mandatory output. Table 5-1 provides an example of a partial list in which the table is ordered by descending damage index. Other orderings are common as, for example, aircraft serial number or damage index by base or model, etc. Table 5-2 provides another example of current status in which the tracking history of each aircraft is presented.

In addition to detailed listings, summaries of the current status provide a quick look capability. Obvious choices for such summaries would be histograms of current damage indices for stratifications of interest. However, another approach is

TABLE 5-1

EXAMPLE IAT OUTPUT—LISTED BY ORDER OF DAMAGE INDEX

TABLE 5-2

EXAMPLE IAT HISTORY FOR INDIVIDUAL AIRPLANE

that of Figure 5-1 which presents a histogram of percent service
life remaining where service life is defined as time to maintenance
action or time to economic life.

5.1.2 Times to Maintenance Action Reports

Since maintenance actions will be scheduled in terms
of potential crack lengths and planned usage, the data system can
be designed to output information regarding the scheduling of
maintenance actions. Obviously straight listings of projected
dates by tail number or analysis location would provide the data
as in Table 5-3. Other types of presentations can be used to
emphasize or summarize.

Table 5-4 graphically displays a projected inspection
schedule for the analysis location of a single airplane. Table 5-5
represents a clever method of displaying the projected distribution
of number of aircraft that will require the maintenance action
during the indicated quarter. The histogram blocks are composed
of the manufacturers serial number so that the histogram also
indicates the prediction of the precise airplanes which will
require the maintenance action.

Figure 5-2 emphasizes the maintenance action. In
this figure, the calendar period during which the action will be
performed is displayed for each coded type of action as defined in
the FSM Plan. Obviously the complete distribution rather than
the mean and range can be presented at the expense of volume of
presentation.

Table 5-6 is an example of a near-term maintenance
action summary. The table indicates the actions that will be
required for each location and airplane in a given time period.

Mo/Yr._____Thru Mo/Yr._____

(FORCE)   (MDS)   (COMMAND)   (BASE)   (WING)

PERCENT SERVICE LIFE REMAINING

Figure 5.1.   Example of Current Distribution of Aircraft
               Structural Life Remaining.

5-6

TABLE 5-3

EXAMPLE IAT OUTPUT-DAMAGE INDEX BY YEAR

```
                                               AIRCRAFT DAMAGE BY YEAR

 ARCFT  BASE LAST *-----------DAMAGE INDEX BY YEAR AND MONTH FOR NEXT SEVENTEEN YEARS------------------------------------*
   SN   CODE DATE  7909  8009  8109  8209  8309  8409  8509  8609  8709  8809  8909  9009  9109  9209  9309  9409  9509  9609

674535     X 7401 0.066 0.066 0.066 0.066 0.066 0.066 0.066 0.066 0.066 0.066 0.066 0.066 0.066 0.066 0.066 0.066 0.066 0.066
674536     X 7512 0.093 0.093 0.093 0.093 0.093 0.093 0.093 0.093 0.093 0.093 0.093 0.093 0.093 0.093 0.093 0.093 0.093 0.093
688220  FTFA 7706 0.094 0.102 0.110 0.118 0.126 0.134 0.142 0.150 0.158 0.167 0.175 0.183 0.191 0.199 0.207 0.215 0.223 0.231
688222  FSPM 7908 0.223 0.237 0.251 0.265 0.279 0.293 0.307 0.321 0.335 0.349 0.363 0.377 0.391 0.405 0.419 0.433 0.447 0.461
688223  FSPM 7705 0.218 0.232 0.246 0.260 0.274 0.288 0.302 0.316 0.330 0.344 0.358 0.372 0.386 0.400 0.414 0.427 0.441 0.455
688224  FTFA 7705 0.129 0.137 0.145 0.153 0.161 0.169 0.177 0.185 0.193 0.202 0.210 0.218 0.226 0.234 0.242 0.250 0.258 0.266
688225  VNVP 7601 0.238 0.238 0.238 0.238 0.238 0.238 0.238 0.238 0.238 0.238 0.238 0.238 0.238 0.238 0.238 0.238 0.238 0.238
688226  FBNV 7704 0.336 0.431 0.526 0.621 0.715 0.810 0.905 0.999 1.094 1.189 1.283 1.378 1.473 1.568 1.662 1.757 1.852 1.946
688227     X 7410 0.358 0.358 0.358 0.358 0.358 0.358 0.358 0.358 0.358 0.358 0.358 0.358 0.358 0.358 0.358 0.358 0.358 0.358
688228  FBNV 7702 0.384 0.479 0.574 0.669 0.763 0.858 0.953 1.047 1.142 1.237 1.331 1.426 1.521 1.616 1.710 1.805 1.900 1.994
688229  VNVP 7601 0.239 0.239 0.239 0.239 0.239 0.239 0.239 0.239 0.239 0.239 0.239 0.239 0.239 0.239 0.239 0.239 0.239 0.239
688230  FBNV 7704 0.360 0.455 0.550 0.644 0.739 0.834 0.928 1.023 1.118 1.212 1.307 1.402 1.497 1.591 1.686 1.781 1.875 1.970
688231  FBNV 7612 0.318 0.413 0.508 0.602 0.697 0.792 0.886 0.981 1.076 1.171 1.265 1.360 1.455 1.549 1.644 1.739 1.833 1.928
696188  FBNV 7612 0.343 0.438 0.533 0.627 0.722 0.817 0.911 1.006 1.101 1.195 1.290 1.385 1.480 1.574 1.669 1.764 1.858 1.953
696189     X 7412 0.185 0.185 0.185 0.185 0.185 0.185 0.185 0.185 0.185 0.185 0.185 0.185 0.185 0.185 0.185 0.185 0.185 0.185
696190  FBNV 7701 0.215 0.310 0.405 0.499 0.594 0.689 0.783 0.878 0.973 1.067 1.162 1.257 1.352 1.446 1.541 1.636 1.730 1.825
696191  FSPM 7908 0.357 0.371 0.385 0.399 0.413 0.427 0.441 0.455 0.469 0.483 0.497 0.511 0.525 0.539 0.553 0.567 0.581 0.595
696192  VNVP 7601 0.056 0.056 0.056 0.056 0.056 0.056 0.056 0.056 0.056 0.056 0.056 0.056 0.056 0.056 0.056 0.056 0.056 0.056
696193  FBNV 7612 0.285 0.380 0.475 0.569 0.664 0.759 0.854 0.948 1.043 1.138 1.232 1.327 1.422 1.517 1.611 1.706 1.801 1.895
696194  FTFA 7909 0.357 0.365 0.373 0.382 0.390 0.398 0.406 0.414 0.422 0.430 0.438 0.446 0.455 0.463 0.471 0.479 0.487 0.495
696195  FTFA 7909 0.332 0.340 0.349 0.357 0.365 0.373 0.381 0.389 0.397 0.405 0.413 0.421 0.430 0.438 0.446 0.454 0.462 0.470
696196  VNVP 7601 0.193 0.193 0.193 0.193 0.193 0.193 0.193 0.193 0.193 0.193 0.193 0.193 0.193 0.193 0.193 0.193 0.193 0.193
696197  XHEA 7909 0.461 0.550 0.639 0.728 0.817 0.906 0.995 1.084 1.173 1.262 1.351 1.440 1.529 1.618 1.707 1.796 1.885 1.974
696198  GAMH 7908 0.417 0.483 0.549 0.615 0.682 0.748 0.814 0.880 0.946 1.012 1.079 1.145 1.211 1.277 1.343 1.410 1.476 1.542
696199  XHEA 7909 0.468 0.557 0.646 0.735 0.824 0.913 1.002 1.091 1.180 1.269 1.358 1.447 1.536 1.625 1.714 1.803 1.892 1.981
696200  XHEA 7909 0.340 0.429 0.519 0.607 0.696 0.795 0.874 0.963 1.052 1.141 1.230 1.319 1.408 1.497 1.586 1.675 1.764 1.853
696201  GAMH 7909 0.444 0.510 0.576 0.642 0.709 0.775 0.841 0.907 0.973 1.040 1.106 1.172 1.238 1.304 1.370 1.437 1.503 1.569
696202  XHEA 7909 0.583 0.672 0.761 0.850 0.939 1.028 1.117 1.206 1.295 1.384 1.473 1.562 1.651 1.740 1.829 1.918 2.007 2.096
696203  XHEA 7909 0.499 0.588 0.677 0.766 0.855 0.944 1.033 1.122 1.211 1.300 1.389 1.478 1.567 1.656 1.745 1.834 1.923 2.012
696205  XHEA 7802 0.388 0.477 0.566 0.655 0.744 0.833 0.922 1.011 1.100 1.189 1.278 1.367 1.456 1.545 1.634 1.723 1.812 1.901
696206  CRWU 7909 0.521 0.589 0.658 0.727 0.795 0.864 0.933 1.001 1.070 1.139 1.207 1.276 1.345 1.413 1.482 1.551 1.619 1.688
696207  GAMH 7909 0.634 0.700 0.766 0.832 0.898 0.965 1.031 1.097 1.163 1.229 1.295 1.362 1.428 1.494 1.560 1.626 1.692 1.759
696208  FFAN 7909 0.422 0.469 0.517 0.564 0.611 0.658 0.705 0.752 0.800 0.847 0.894 0.941 0.988 1.036 1.083 1.130 1.177 1.224
696209  GAMH 7909 0.675 0.741 0.907 0.973 0.939 1.005 1.072 1.138 1.204 1.270 1.336 1.402 1.469 1.535 1.601 1.667 1.733 1.800
696210  VSRE 7909 0.424 0.485 0.545 0.605 0.665 0.725 0.785 0.846 0.906 0.966 1.026 1.086 1.147 1.207 1.267 1.327 1.387 1.448
696212  FFAN 7909 0.634 0.681 0.728 0.776 0.823 0.870 0.917 0.964 1.011 1.059 1.106 1.153 1.200 1.247 1.294 1.342 1.389 1.436
696213  XHEA 7909 0.450 0.539 0.628 0.717 0.806 0.895 0.984 1.073 1.162 1.251 1.340 1.429 1.518 1.607 1.696 1.785 1.874 1.963
696214  WYTD 7909 0.511 0.547 0.583 0.618 0.654 0.690 0.725 0.761 0.797 0.833 0.868 0.904 0.940 0.975 1.011 1.047 1.083 1.118
696215  VSRE 7909 0.474 0.534 0.594 0.654 0.714 0.775 0.835 0.895 0.955 1.015 1.076 1.136 1.196 1.256 1.316 1.376 1.437 1.497
696216  WYTD 7909 0.497 0.533 0.569 0.604 0.640 0.676 0.711 0.747 0.783 0.819 0.854 0.890 0.926 0.961 0.997 1.033 1.069 1.104
696217  VGLZ 7909 0.465 0.506 0.547 0.588 0.629 0.670 0.711 0.752 0.793 0.834 0.875 0.917 0.958 0.999 1.040 1.081 1.122 1.163
696218  XHZG 7909 0.455 0.508 0.561 0.614 0.667 0.720 0.773 0.827 0.880 0.933 0.986 1.039 1.092 1.145 1.198 1.252 1.305 1.358
696219  LUXC 7909 0.359 0.399 0.439 0.479 0.519 0.560 0.600 0.640 0.681 0.721 0.761 0.802 0.842 0.883 0.923 0.963 1.004 1.044
696221  XHZG 7909 0.468 0.521 0.574 0.627 0.680 0.734 0.787 0.340 0.893 0.946 0.999 1.052 1.105 1.159 1.212 1.265 1.318 1.371
696222  WAAR 7909 0.373 0.414 0.455 0.495 0.536 0.576 0.617 0.657 0.698 0.738 0.779 0.820 0.860 0.901 0.941 0.982 1.022 1.063
696223  FFAN 7909 0.478 0.525 0.572 0.619 0.666 0.714 0.761 0.808 0.855 0.902 0.949 0.997 1.044 1.091 1.138 1.185 1.233 1.280
696224     X 7506 0.203 0.203 0.203 0.203 0.203 0.203 0.203 0.203 0.203 0.203 0.203 0.203 0.203 0.203 0.203 0.203 0.203 0.203
696225  FFAN 7909 0.433 0.481 0.528 0.575 0.622 0.669 0.717 0.764 0.811 0.858 0.905 0.952 1.000 1.047 1.094 1.141 1.188 1.235
696226  WAAR 7909 0.401 0.441 0.482 0.522 0.563 0.603 0.644 0.685 0.725 0.766 0.806 0.847 0.887 0.928 0.968 1.009 1.050 1.090
696227  VSRE 7909 0.397 0.457 0.517 0.578 0.638 0.698 0.758 0.818 0.879 0.939 0.999 1.059 1.119 1.179 1.240 1.300 1.360 1.420
696228  RDRD 7701 0.338 0.363 0.389 0.415 0.441 0.466 0.492 0.518 0.544 0.569 0.595 0.621 0.646 0.672 0.698 0.724 0.749 0.775
696229  XHZG 7909 0.403 0.456 0.509 0.562 0.615 0.668 0.721 0.775 0.828 0.881 0.934 0.987 1.040 1.093 1.146 1.199 1.253 1.306
696230  VSRE 7909 0.473 0.533 0.594 0.654 0.714 0.774 0.834 0.894 0.955 1.015 1.075 1.135 1.195 1.256 1.316 1.376 1.436 1.496
696231  WAAR 7909 0.353 0.394 0.434 0.475 0.515 0.556 0.596 0.637 0.677 0.718 0.759 0.799 0.840 0.880 0.921 0.961 1.002 1.043
696232  XHZG 7909 0.456 0.509 0.563 0.616 0.669 0.722 0.775 0.828 0.881 0.934 0.988 1.041 1.094 1.147 1.200 1.253 1.306 1.359
696233  WAAR 7909 0.451 0.492 0.532 0.573 0.613 0.654 0.694 0.735 0.776 0.816 0.857 0.897 0.938 0.978 1.019 1.059 1.100 1.141
696234     X 7305 0.154 0.154 0.154 0.154 0.154 0.154 0.154 0.154 0.154 0.154 0.154 0.154 0.154 0.154 0.154 0.154 0.154 0.154
```

TABLE 5-4

EXAMPLE INDIVIDUAL AIRCRAFT INSPECTION SCHEDULE
FOR ANALYSIS LOCATIONS RANKED BY INSPECTION DATE

Mo/Yr _____ thru Mo/Yr _____

(FORCE)   (MDS)   (COMMAND)   (BASE)   (WING)

A/F Ser. No. _____   Flight Hrs. _____   Total Ldg. _____
HFR Ser. No. _____   Airframe Hrs. _____   Full Stop _____
                                                          Touch & Go _____

Analysis Location (ranked): 5, 3, 7, 2, 8, 6, 4, 10, 13, 9, 12, 1, 17, 20, 19, 16, 14, 18, 15, 11 — plotted against months J F M A M J J A S O N D for years 1980, 1981, 1982.

TABLE 5-5

EXAMPLE DISTRIBUTION OF MAINTENANCE ACTION WHICH ALSO
INDICATES DATES OF ACTION FOR INDIVIDUAL AIRPLANES

Figure 5-2. Example Schedule for Maintenance for Various Actions for a
Defined Usage Action Required Prior to Retirement.

5-10

TABLE 5-6

EXAMPLE FISCAL YEAR 1980 INSPECTION PLAN

DATE: _____

AIR FORCE SERIAL NO.	MFR. Serial NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
648304	2	X	X		X		X								
648307	3	X	X		X		X								
648310	7	X		X	X	X	X								
648322	6		X			X									
648421	15		X		X	X	X								
648316	18			X	X	X	X								
630210	27		X		X		X								
600301	41				X		X								
600225															
600228	13														

(Force) (MIS) (Command) (Base) (Wing)

ANALYSIS LOCATION

5-11

5.1.3   Trends in Usage Reports

Usage trends will depend on a large degree on the available data. If mission data is a part of the IAT or L/ESS functions, then trends in the usage can be described by data tabulations as in the example of Table 5-7 or in computer generated plots as in the examples of Figures 5-3 through 5-6. For selected control locations, usage trends can also be monitored in terms of standardized crack growth (Figure 5-7). Figure 5-8 is an example of a summary which displays potential crack lengths at one critical point for all aircraft and the projected crack growth at the critical point under baseline usage.

5.1.4   Usage Change Detection From IAT Data

Most tracking systems are based to some extent on the correlation of monitored usage parameters with potential crack length at critical points. The correlation is valid in a statistical sense as long as operational usage is consistent with the usage from which the correlation was derived. For example, assume potential crack (or damage index) is calculated as a linear function of only flight time and number of exceedances of levels of acceleration at the center of gravity. Then, the correlation is dependent on the assumption that aircraft weights in the future will be equivalent to those for which the damage index linear function was derived. Further, given a current potential crack length, the projection of time to maintenance action is based on the assumption that future usage is consistent with the planned usage of the projection. Since changes in usage can have a significant effect in predictions and since usage changes do occur without being documented, the Force Management data package should be designed to detect usage changes at any level consistent with the requirements of the total data package.

The trends in usage reports of the previous paragraph are examples of reports which can indicate usage changes. The projected month to maintenance can also be used to statistically test for changes in usage if data files are maintained which preserve past potential crack length estimates or times to projected maintenance actions for each aircraft.

5-12

TABLE 5-7

EXAMPLE TREND ANALYSIS OF MAJOR MISSION
PARAMETERS (FOR DERIVED STRATIFICATION)

DATE: _____

TOTALS	QUARTERLY SUMMARY						YEARLY SUMMARY BASED ON DESIGNATED 4 QUARTERS				YEARLY SUMMARY (FISCAL OR CALENDAR)			
	Q6 783	Q5 784	Q4 791	Q3 792	Q2 793	Q1 794	Q7-Q4 782-791	Q6-Q3 783-792	Q5-Q2 784-793	Q4-Q1 791-794	1976	1977	1978	1979
Active Aircraft														
Reported														
Planned														
Flight Hours														
% Logged														
Reported														
Ave. for A/C														
Reported for A/C														
Planned for A/C														
Airframe Hours														
Reported														
Ave. Per A/C														
Ave. Per Flight														
Reported Per A/C														
Planned for A/C														
Reported Per Flight														
Planned Per Flight														
Flight Duration														
Ave. Per Flight														
Reported Ave.														
Planned Ave.														
Flights														
Reported														
Ave. Per A/C														
Ave. Per Flight														
Reported Ave.														
Planned Ave.														
Landings-Total														
Reported														
Ave. Per A/C														
Ave. Per Flight														
Reported For A/C														
Planned Per A/C														
Reported Per Flight														
Planned Per Flight														
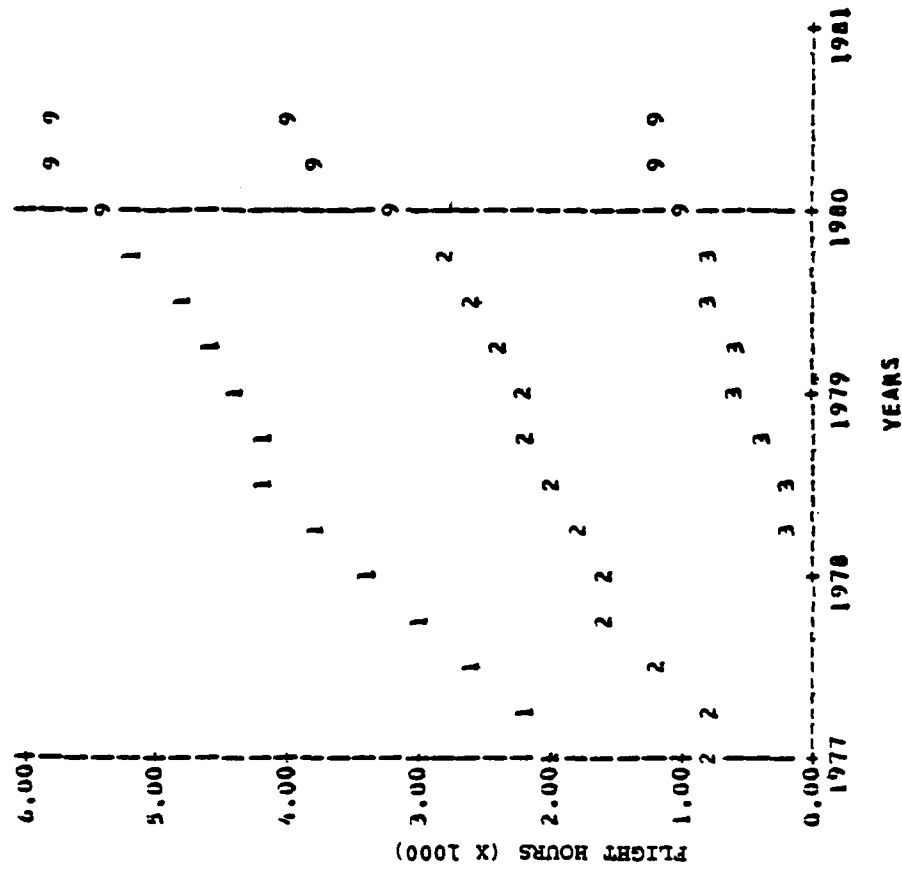
Figure 5-3. Example Cumulative Flight Hours Per Aircraft.
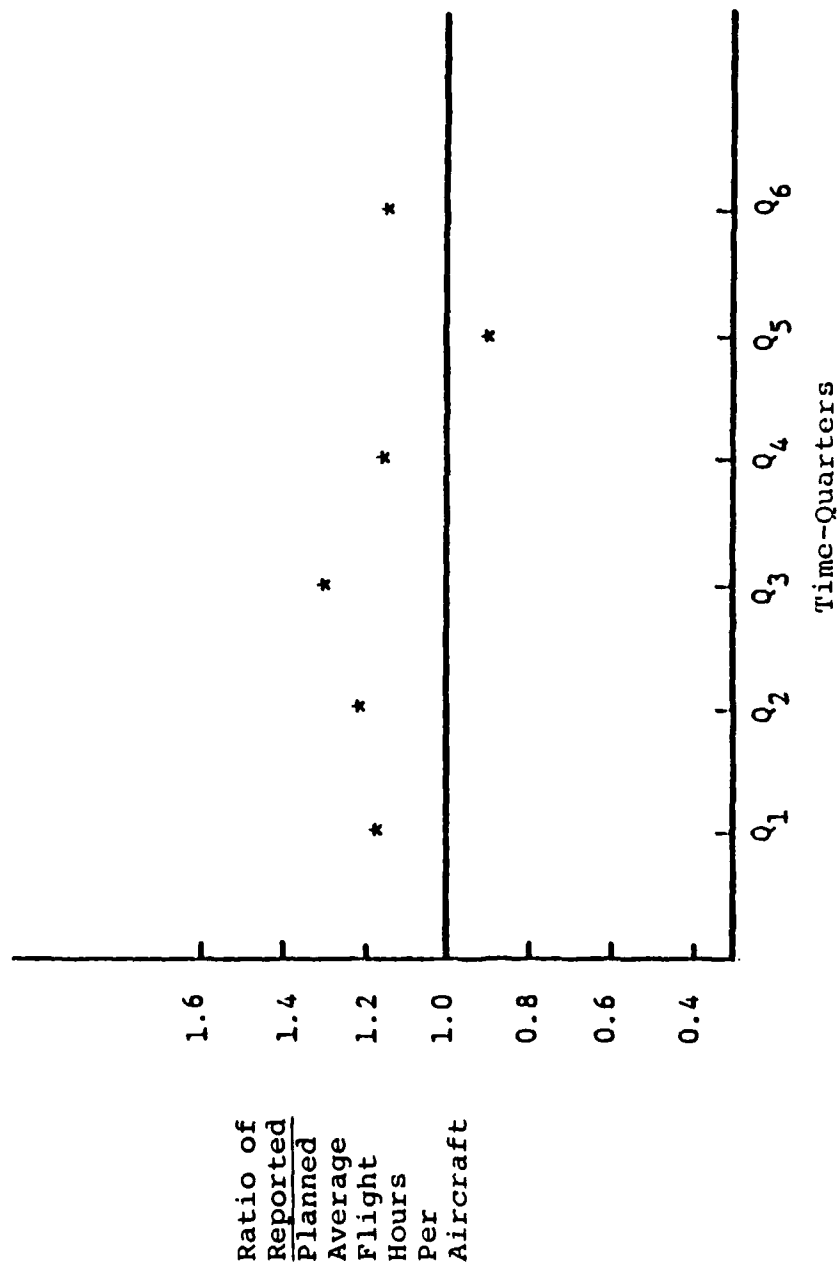
Figure 5-4.   Example Ratio of Reported/Planned Average Flight Hours
Per Aircraft for Six Quarters.
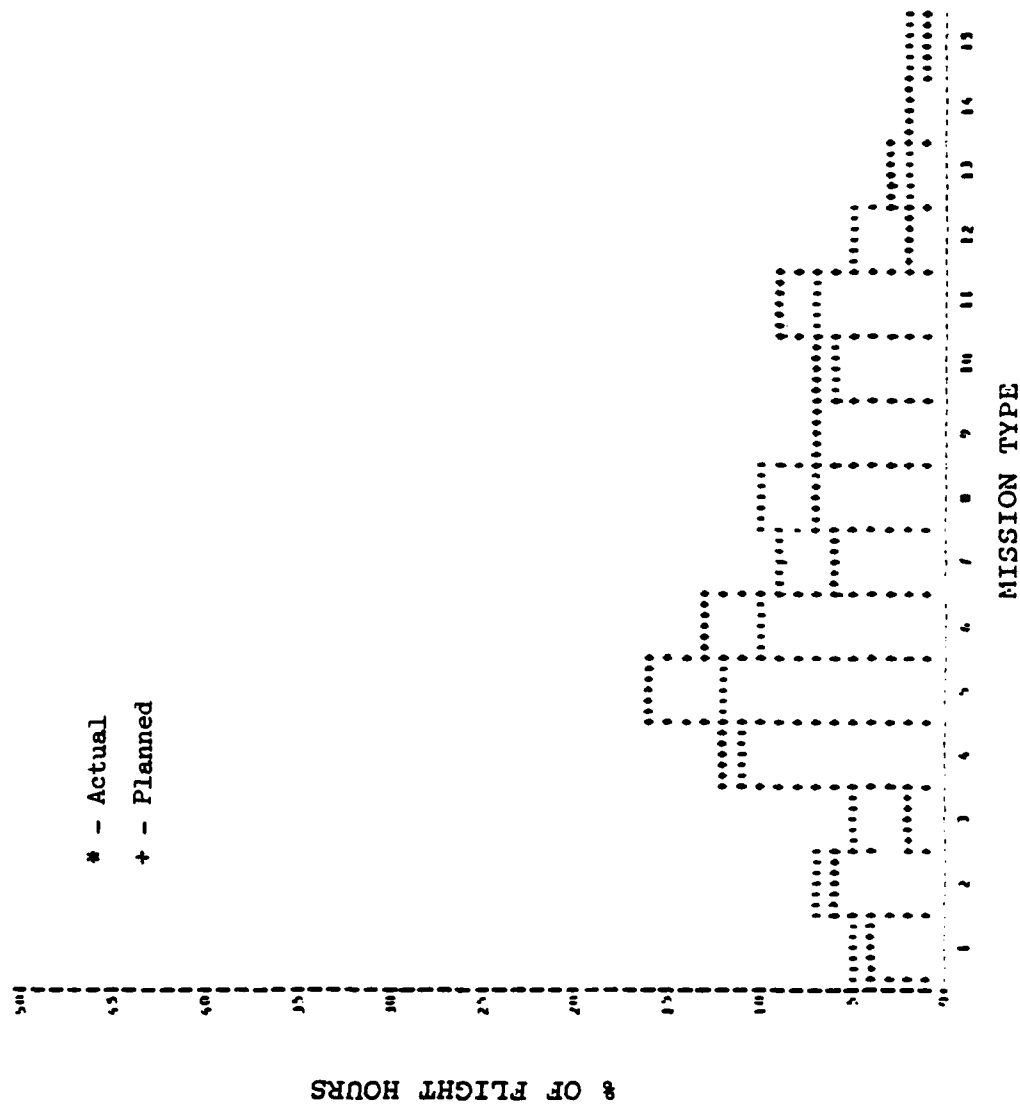
Figure 5-5. Example Distribution of Flight Hours by Mission Type.

* Reported
+ Planned
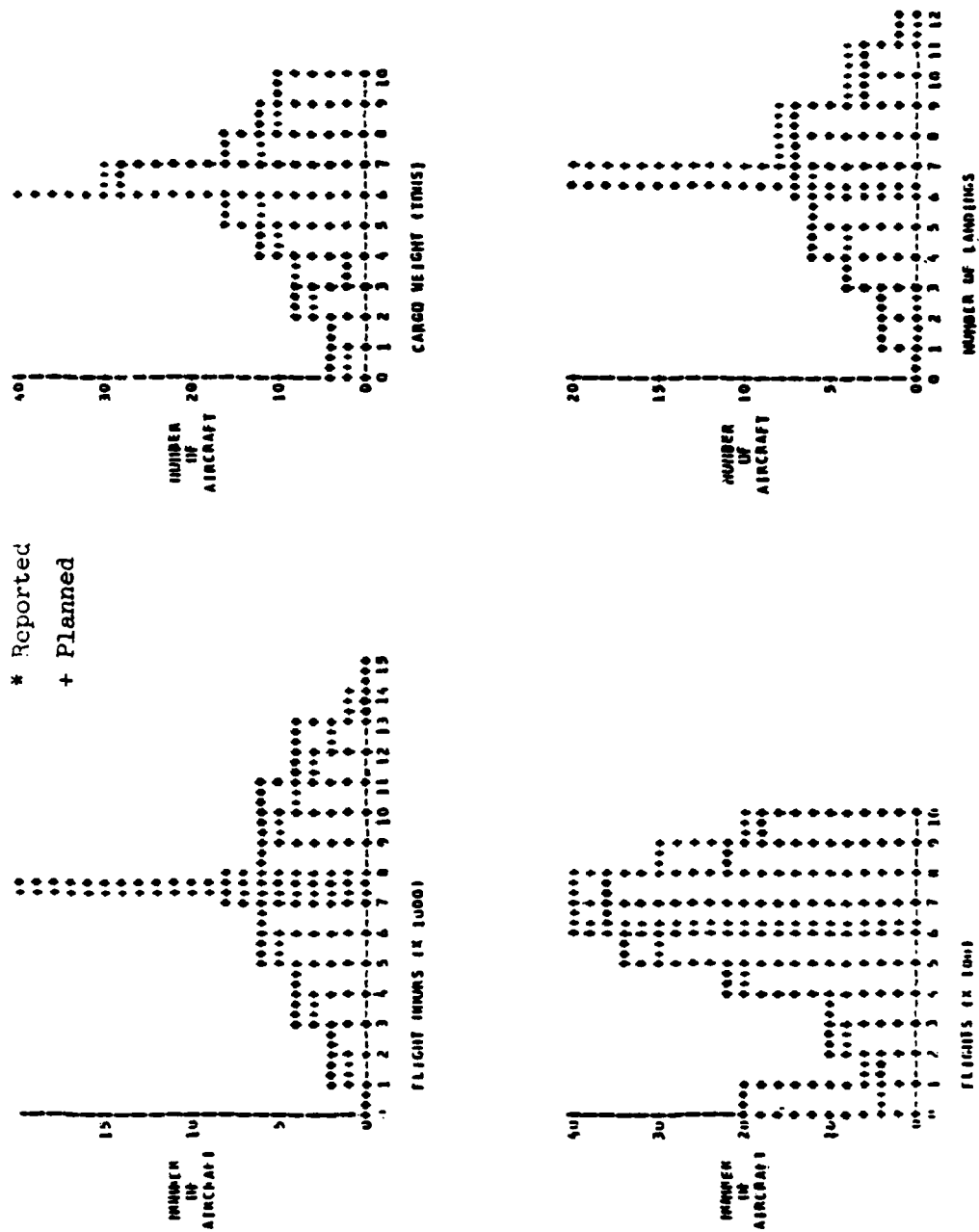
Figure 5-6.   Example Summaries of Mission Parameters.

(Force)　　　　(MDS)　　　(Command)　　　(Wing)　　　(Base)

Analysis Location_____
No. of Aircraft_____

——○—— 90%
——*—— Ave.
——◇—— 10%
— — — — Planned

Standardized Crack Growth Per Flight Hour $\Delta a/\Delta t_{a/c}$

20.0

16.0

12.0

8.0

4.0

0.0

1976　　1977　　1978　　1979　　1980
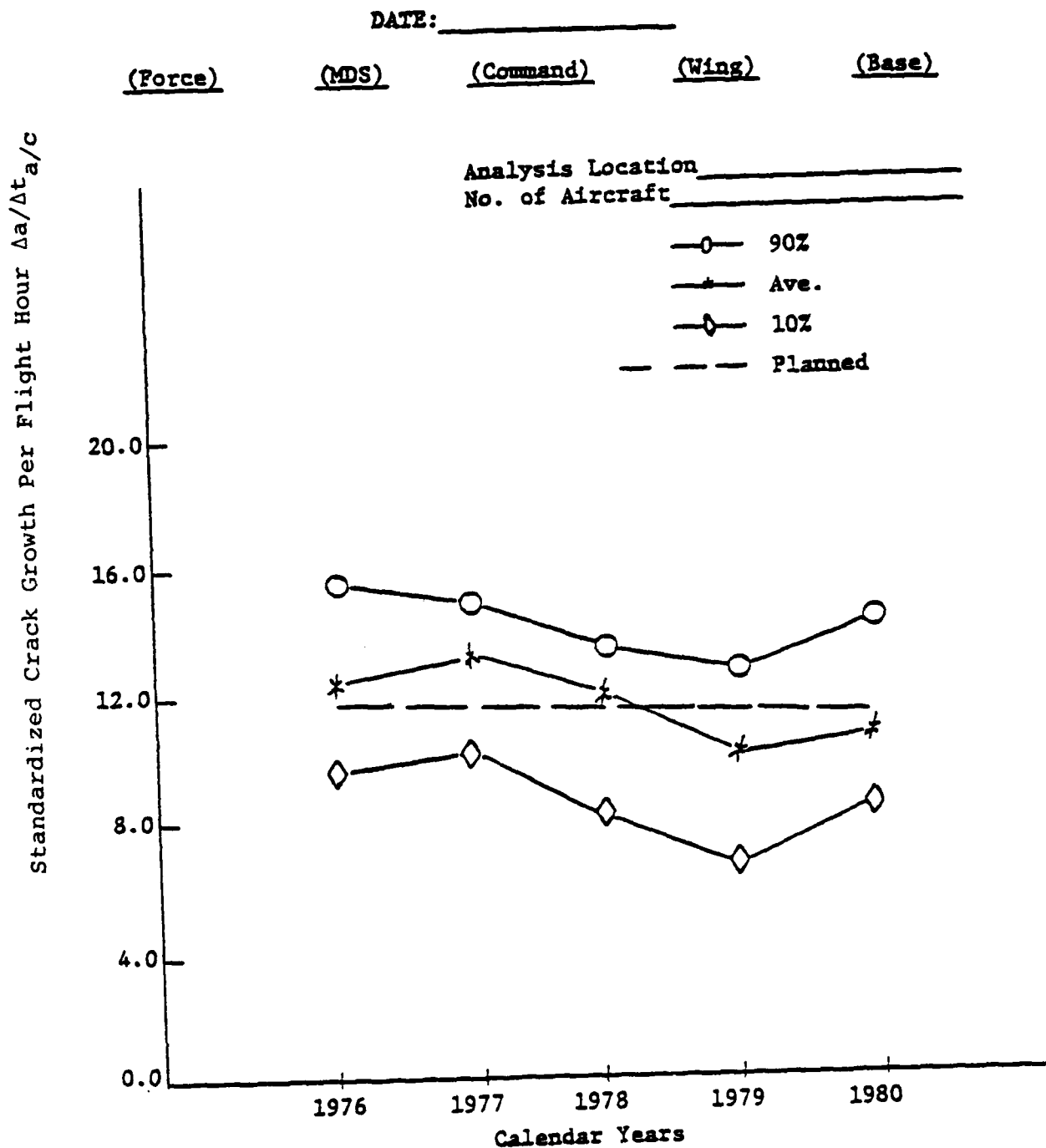
Calendar Years

Figure 5-7.　　Example Average Standardized Crack Growth Rate
Versus Calendar Years.
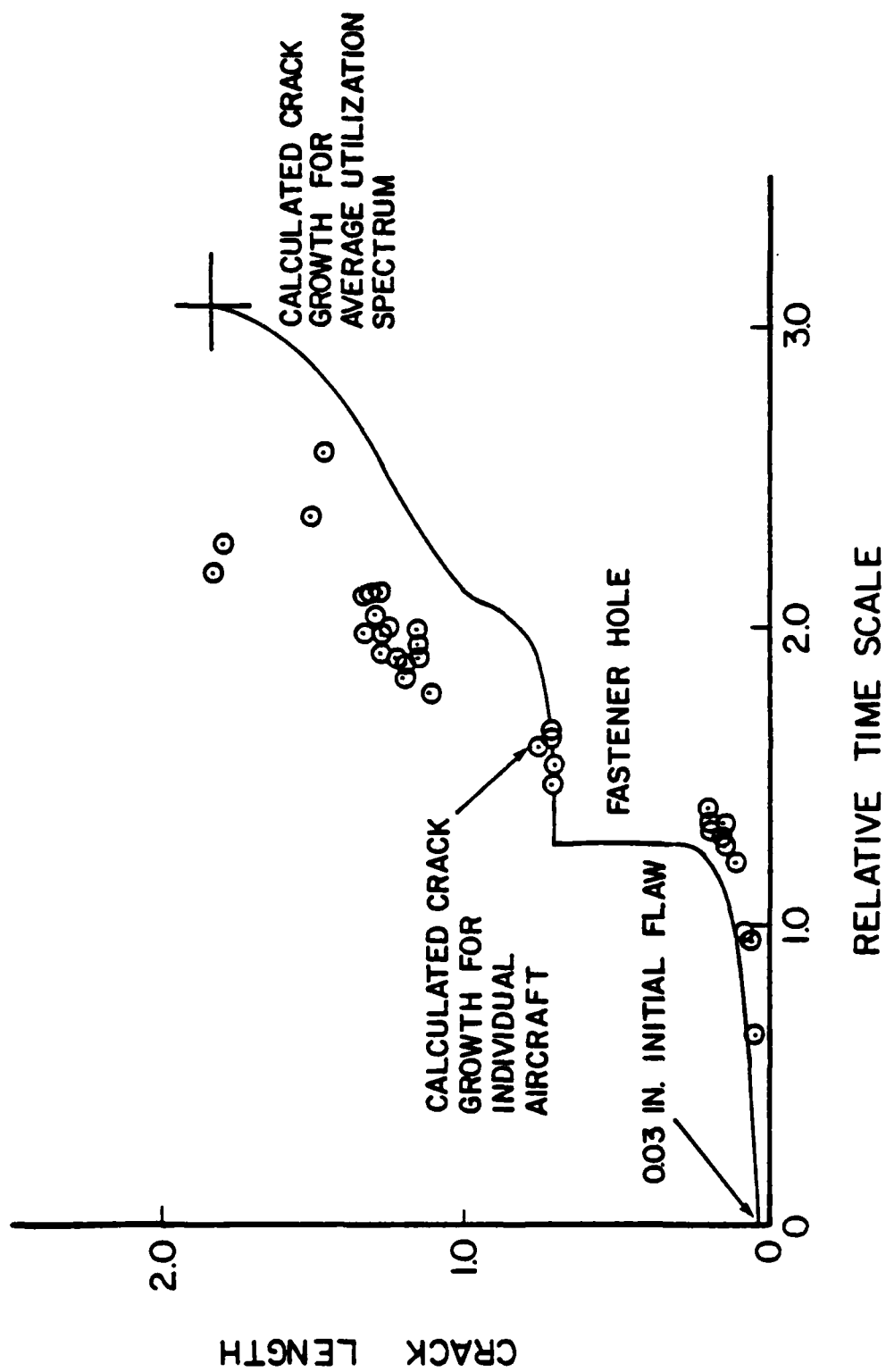
Figure 5-8. Fracture Tracking Analysis Point W-XX.

One data product of an IAT update is a prediction of calendar months to maintenance action for one control point in each airplane. This prediction is based on assumptions regarding future usage. If, over a fixed time period, the usage is consistent with planned, the changes in the projections should be consistent. On the other hand, if the projections are not consistent over the period, the aircraft are being flown differently than planned and a bias is being introduced into the projected times to maintenance actions. This bias could influence the long-range planning of the financial, personnel, spares and facility resources required by the maintenance actions.

Since the planned or FSM crack growth usage is defined for an "average" aircraft, changes in usage must be detected by considering changes in average projected months to maintenance action. Let $L_{i,j}$ represent the predicted months to maintenance action for airplane j at calendar data D_i. Similarly, $L_{i+1,j}$ represents the predicted months to maintenance action at D_{i+1}. If the airplane had been flown exactly as planned

$$L_{i,j} - L_{i+1,j} = D_{i+1} - D_i \qquad (5-1)$$

Since the tracking program is updated for all aircraft at the same time, the months between updates do not depend on the individual aircraft and is known exactly (e.g. 6 months). Therefore, by considering the differences in projected months to maintenance actions $(L_{i,j} - L_{i+1,j})$ to be a random variable, the statistical properties of $(L_{i,j} - L_{i+1,j})$ can be analyzed. In particular, a test of the hypothesis

$$H_o: \quad \overline{L_{i,j} - L_{i+1,j}} - (D_{i+1} - D_i) = 0$$

versus

$$H_1: \quad \overline{L_{i,j} - L_{i+1,j}} - (D_{i+1} - D_i) \neq 0$$

can easily be performed for those subsets of the force which are assumed to have the same usage and for which there are sufficient aircraft to assume normality of the sample averages. This formulation assumes that the experience of the individual aircraft in the period is representative for the population and that the severity of usage for individual airplanes in one period is independent of that in the next. When the test indicates a significant difference between maintenance dates for the two periods, a follow-up analysis will determine if the difference is due to changes in the flying rate or changes in stress spectrum severity. A test on the average flying rate can easily be performed since the total flight hours of each individual aircraft are routinely reported as part of an IAT output.

5.2 INDIVIDUAL AIRCRAFT TRACKING METHODS

Methods for performing the IAT function are centered on the collection, processing, and analysis of the data which is indicative of usage severity for each individual airplane. The following paragraphs present a discussion on the selection of tracking parameters and a summary of current methods (usage forms, counting accelerometer and strain recorders) and methods which are expected to become operational in the near future (microprocessor based systems and crack growth gage based systems). The methods are categorized by major data source rather than method of analysis.

5.2.1 IAT Parameter Selection

The choice of the tracking parameters is determined in conjunction with the analysis method for estimating potential crack growth. The output of the tracking system must be based on or contain an estimate of potential crack length at the critical points and crack growth as determined by the local stress history. Therefore, the analysis system must be capable of correlating the IAT parameters with stress histories and/or potential crack growth. The attack/fighter/trainer (A/F/T) and the transport/bomber (T/B) classes of aircraft have basically different flight operations, different primary sources of crack driving stresses, and different degrees of difficulty in the transfer of stresses. These differences produce requirements on the IAT analysis methods which tend to be aircraft class specific.

5.2.1.1 IAT Parameters For A/F/T Aircraft

Potential cracks in A/F/T class of aircraft are driven by stresses that result primarily from pilot induced maneuvers. Therefore, IAT tracking parameters for A/F/T aircraft are generally measures of the frequency and severity of the maneuvers that are performed during the monitored time period. Currently, such measures include stress measurements at selected locations on the aircraft and counts of normal acceleration levels at the aircraft center of gravity. These basic

activity indicators may or may not be supplemented with other data descriptive of the operations. These other data would include such items as date of flight, base of operations, length of flight, mission code, fuel weight, configuration, store weights, number of landings and refuelings.

The stress or normal acceleration data are generally related to crack growth at critical locations by statistical methods which will be summarized later. Cycle by cycle crack growth analyses can be performed from the stress data if the stress histories are preserved and can be transferred to stress peaks at the critical locations of interest. Since only weak correlation exists between tail stresses and wing stresses or normal acceleration, activity indicators indicative of the magnitude of tail stresses could be introduced. These could include stress measurement at tail critical locations or measurements of lateral acceleration at the center of gravity. Although other aircraft motion parameters (e.g. roll, pitch and yaw accelerations) could be monitored, the added complexity and cost of collecting and processing the resulting much larger mass of data would not be warranted. The tracking function in A/F/T aircraft can be adequately met by monitoring the results of the stress environment at a judiciously selected set of locations. Therefore, tracking systems in future A/F/T aircraft will probably be based on the primary IAT parameters of stresses or measurements from a crack growth gage.

It should be noted that some A/F/T aircraft types (e.g. the T-38 in normal training operations) are operated in a consistent fashion. For these aircraft the IAT function can be adequately met by data from flight logs. The L/ESS data is used to model the stress histories during the operations and to establish the correlation between flight log information and potential crack length.

5.2.1.2 IAT Parameters For T/B Aircraft

Transport/bomber aircraft are large and flexible and are more sensitive to the high frequency loads caused by turbulence and ground operation than to low frequency maneuver loads. The dynamic response to those loads may make it impossible to compute stress histories or correlate potential crack growth over the entire airframe from a few monitored stresses. Therefore, it is considered more accurate to monitor occurrences and durations of flight conditions and to infer the resulting potential crack growth from the L/ESS data sample which describes the flight condition.

Different aircraft types are sensitive to different events or parameters which define a flight condition. Table 5-8 presents a summary of IAT input data which are recorded on current T/B aircraft. Note that an item which can be repeatedly or continuously recorded is called a parameter while an infrequent entry which is reasonably independent of other parameters is called entry or event. This table lists 49 different data items. In an effort to identify the more universal items, a parameter (or event) is called common if it is being recorded for three or more aircraft types. Table 5-9 lists the common data and contains 16 parameters and 8 entry/events. These data are representative of the types of data required by current usage forms IAT systems.

In T/B Force Management, the data collected under the IAT program is used extensively beyond the estimation of current potential crack length and predicted time to maintenance actions. Therefore, even if strain (stress) measurements or measurements from a crack growth gage at selected locations are determined to be advantageous, they can only be considered as a supplement to the primary data source which defines the flight conditions.

TABLE 5-8

REVIEW OF USAGE FORM IAT
INPUT DATA AND PARAMETERS

PARAMETER	C5A	C130	C/KC 135	C141	FB-111A	ENTRY/ EVENT OR PARAMETER
ACFT. TAIL NO.	X	X	X	X	X	E
USAGE LOG NO.	X					E
SEQUENCE NO., SORTIE NO.	X	X	X	X		E
AIRFRAME HOURS	X	X	X	X	X	E
OPERATIONAL MAINTENANCE SQUADRON	X					E
TIME (DAY, MONTH, YEAR, ZULU TIME)	X	X	X	X	X	E,P
INITIAL TAKEOFF EVENT (WHEN)	X	X	X	X		P
GROSS WEIGHT	X	X	X	X	X	P
FUEL WEIGHT	X	X	X	X		P
CARGO WEIGHT	X	X	X	X	X	P
CENTER OF GRAVITY	X					E
ICAO CODE-TAKEOFF; LANDING	X	X	X	X		E
CRUISE PERIOD (1,2,3,4)	X	X		X		E
MACH OR AIRSPEED	X	X	X	X		P
ALTITUDE	X	X	X	X		P
TOUCH & GO EVENTS (WHEN)	X	X	X	X	X	P
FULL STOP LDGS & TAKEOFFS (WHEN)	X	X	X	X	X	P
INFLIGHT OPERATIONS EVENTS	X					P
(PARAMETERS RELATED TO REFUELING, AIRDROP, CARGO AND FUEL JETTISON, AND TERRAIN FOLLOWING)						

TABLE 5-8 (CONTINUED)

REVIEW OF USAGE FORM IAT INPUT
DATA AND PARAMETERS

PARAMETER	C5A	C130	C/KC 135	C141	FB-111A	ENTRY/ EVENT OR PARAMETER
TOTAL TIME OF FLIGHT	X		X	X		E
RUNWAY CODE		X				E
COMMAND, WING, SQUADRON, HOME STA. ACFT. COMMANDER		X		X		E
FLIGHT, ENGR. COMPLETED/CHECKED BY	X	X	X	X		E
REMARKS	X		X			E
FINAL LANDING EVENT (WHEN)	X	X	X	X		P
NORMAL OR MAX. TAKEOFF, LDG.		X				P
TAXIWAY CODE; TAXI TIME		X				P
FUEL DISTRIBUTION		X				P
AIRDROP/REFUEL WEIGHT		X		X		P
CONTOUR FLYING		X		X		P
EXTERNAL STORES WEIGHT		X			X	P
OPERATIONAL PHASE (CLIMB, CRUISE, FUEL ON LOAD, FUEL OFFLOAD, DESCENT, TRAFFIC)			X	X		P
RESERVE FUEL (FULL, EMPTY)			X			P
TOTAL LANDINGS			X			E

TABLE 5-8 (CONCLUDED)

REVIEW OF USAGE FORM IAT INPUT
DATA AND PARAMETERS

PARAMETER	C5A	C130	C/KC 135	C141	FB-111A	ENTRY/ EVENT OR PARAMETER
DUTY AF BASE; PHONE			X			E
FULL STOP LANDINGS, TOTAL LANDINGS AT START				X		E
FUEL WEIGHT ON FINAL LANDING	X	X	X	X	X	P
ALL WEATHER LANDING SYSTEM LANDINGS				X		P
AIRDROP				X		P
N_Z COUNTS					X	P
MISSION IDENTIFICATION					X	P
LOW-ALTITUDE HIGH SPEED USAGE					X	P
WING SWEEP ANGLE					X	P
NO. LOW APPROACHES					X	E
NO. GEAR RETRACTIONS					X	E
BARRIER ENGAGEMENT EVENT					X	E
EVASIVE MANEUVERS EVENT					X	E
AIR REFUELING EXTERNAL TANKS EVENT					X	E
TOTAL	23	23	21	24	18	

TABLE 5-9

USAGE FORM IAT - COMMON INPUT DATA AND PARAMETERS

INPUT DATA (ENTRY/EVENT)

AIRCRAFT TAIL NO.
AIRFRAME HOURS
TAKEOFF BASE
LANDING BASE
TIME(DAY, MONTH, YEAR)
SEQUENCE NO., SORTIE NO.
TOTAL TIME OF FLIGHT
WHO COMPLETED/CHECKED THE FORM

PARAMETER

CLOCK TIME (Z)
GROSS WEIGHT
CARGO WEIGHT
FUEL WEIGHT
EXTERNAL STORES WEIGHT
INITIAL TAKEOFF (WHEN;FUEL WEIGHT)
OPERATIONAL PHASE
AIRSPEED
ALTITUDE
TOUCH-AND-GO EVENTS
FULL-STOP LANDINGS & TAKEOFF
CONTOUR FLYING
AIRDROP/REFUEL WEIGHT
FINAL LANDING (WHEN;FUEL WEIGHT)

5.2.2 Usage Forms

Usage forms based IAT systems are based on an analysis system in which flight profile data are recorded by a crew member during a flight and the recorded description of the activity of the flight is converted to potential crack growth through parametric or statistical methods. In most usage forms IAT programs, potential crack growth is modeled in terms of time in flight condition or mission type and/or counts of discrete events (ground-air-ground cycles, landings, etc.). Usage forms tracking is the only T/B tracking method currently in use.

The C-141 IAT program provides an example of a program based on usage forms. This crack growth based program operates on crew data sheet (usage form) entries to define typical "missions", including mission sequence. Provisions for special mission definitions are generally included. Incremental analytical crack length from an assumed initial flaw is calculated for each structural monitor location for each mission in sequence. The incremental crack length adds to the total length produced by the previous missions, and the new total length establishes the parameters for calculation of the incremental length produced by the next mission. The predicted future crack extension is calculated using analytical forecasting usage for that aircraft. Force Maintenance Actions (i.e. time to modification or inspection) are defined based on this prediction. Inspection permits the resetting of the calculated crack length to the NDI detectable crack size in that inspection, as appropriate.

Usage forms IAT programs (and any other IAT programs also) require supplemental data and cost-effective program design. The 'Usage Forms' IAT based on crack growth calculations and NDI results requires a 'closed loop' for complete use of the program. As each tail number is inspected at the monitor locations a reporting system is required to feed that data back to the ASIP manager so that the 'next interval' projections can be provided. Without this 'feed back' the NDI results of cracks (if any) will have to be assumed which could adversely affect Force Safety. The 'Closed Loop' concept will require the ALCs to implement the necessary reporting system.

The usefulness of a 'forms based' IAT and closed loop NDI reporting system is very dependent on the format for all output data to the ASIP manager. A potential limitation exists if the output format is not structured to be responsible to the practical needs of the USAF user.

Usage forms IAT programs required to generate the output needed for Force maintenance 'Actions' require careful scrutinizing in order to produce data at reasonable costs. Current state-of-the-art crack growth 'damage' calculation routines are available at competitive rates compared to previous routines. Initial costs will obviously be incurred to get the data 'on-line' for the various airframes. A practical and responsive Force Maintenance IAT program based on NDI and crack growth has the potential to achieve lower PDM maintenance burdens than are currently required.

5.2.2.1 Advantages and Limitations

Usage forms IAT programs are based on data block utilization breakdowns or on predefined mission descriptions obtained by computer analyses of crew data sheet (usage form) entries. The data base for the analyses includes flight loads and ground loads surveys, loads and environmental stress spectra (L/ESS) data, dynamic response tests and analyses, fatigue tests and analyses, and predicted and actual aircraft utilization data. The programs are updated periodically through Service Life Analyses to include the results of tests, service aircraft utilization, service aircraft corrosion/cracking experience, and analyses of these data obtained subsequent to the last update. Usage forms IAT programs offer significant advantages, which include:

Updated data base (reanalysis). The tracking program is recommended to be preceded by a thorough durability and damage tolerance assessment (DADTA), in which the entire aircraft structure is reviewed in the light of all design, development, test, and service experience obtained to date. Critical locations are defined and crack growth analyses are performed to identify inspection and modification actions based on DADTA crack growth concepts. IAT structural monitor locations and the design of the tracking

program are thus structured to the results of the intensive
DADTA. The resulting program completes an updating of the total
structural analysis to present MIL-STD-1530A Aircraft Structural
Integrity Program (ASIP) concepts.

Refinement - The programs are based on all
past and current design, development, testing, and operational
aircraft data.

Consistency - The methods used are consistent
with the original design concepts and subsequent development, test,
and analysis methods.

Flexibility - Sufficient data are obtained
so that history can be reconstructed or reanalyzed if necessary.

Simplicity - The basic methodology and
calculation routines are straightforward.

Responsive to General Structural
Characteristics - Responsive to crack growth
characteristics, geometry, material, stress levels, environment
(moisture, corrosive products, fuel), and design and manufacturing
characteristics which are major influences on crack growth rate at
a specific location. These are all included in the crack growth
analysis on which the IAT program is based.

Responsive to NDI Results - Scheduled safety
inspections for critical areas are responsive to results of NDI.
The reliable detectable crack size at a given location by NDI and
the crack growth analysis form the basis of establishing the
recurring 'Next Interval' of flying for the particular tail number.

Responsive to Critical Crack Length - The
time to inspection or modification is based on crack growth calcu-
lations which utilize critical crack length determinations for
selected tracking points.

Current Force Maintenance Action Response -
Inspection actions are based on crack growth from a pre-defined
'safety' based initial crack length or an inspection - detectable
length, thus providing force safety responsiveness to fly the

5-31

'next interval' based on most recent NDI results and the usage of the particular individual aircraft.

A Transport/Bomber 'Usage Forms' IAT program is limited by the effects of:

Reliance on average mission and environmental data - Any usage forms tracking program must use statistical data for load or stress occurrences per data block or per mission, and the sequencing of these occurrences. The specific loads and sequence experienced by the individual aircraft are not defined.

Limited Sequencing Data for Past Usage - Historical individual aircraft usage information may not have been stored in flight sequence. Future IAT programs based on crack growth require a recognition and accounting for sequence. Unsequenced historical data can only be reconstructed to an accuracy of so many missions in a given quarter. Random sequencing or other analytical means of reconstructing the history within the quarter is necessary.

5.2.2.2 Stress Relationship

Transport/Bomber usage form Individual Aircraft Tracking (IAT) programs generally have individual, independently produced structural monitor location analyses. The individual monitor locations are anticipated to apply to zones or regions of structure whose boundaries are to be determined by detail structural analysis which considers stress level, local geometry and manufacturing/fabrication factors. Normalized crack growth evaluations would be performed to assist in broadening the 'zones' covered by a single monitor location. Stress transfer functions will be used in conjunction with other methods as discussed in a total sensitivity analysis in arriving at the final 'zonal' coverage.

For crack growth IAT, the thorough DADTA which should precede the design of the IAT program would be used to define specific critical locations for the IAT program. The final number of recommended monitor locations would be selected as necessary in order to obtain the necessary IAT data to respond to the sensitivity of the particular structural configuration and utilization.

5.2.2.3 Crack Growth Models/Examples

There are basically three approaches to modeling potential crack growth from usage form data. The most general of these simply converts flight hours and number of landings to crack growth. The second approach uses the flight data to correlate the flown mission with a crack growth increment which has previously been defined for similar missions. The third approach uses the recorded data to identify time in data blocks (as defined by weight, airspeed, altitude, configuration, special events, etc.) and correlates this time with incremental crack growth. The following paragraphs summarize these three approaches.

Flight Hours/Landing Method

This is the simplest IAT system possible and is probably sufficient for an aircraft in which all control points are flight critical and all missions (or mixtures of missions) are very similar. However, this very simple method is also present to some extent in most tracking systems since it is generally used as a gap-filling technique to account for missing flight time when other recording methods fail. Also, many aircraft are tracked by flight hours to some extent with some structural inspections scheduled on the basis of flight hours.

Figure 5-9 is a schematic of the flight hours/landings tracking method. Flight hours and landings are reported as part of the individual airframe operation and maintenance records. A relation between crack growth and flight hours or landings is determined for a composite mission mix based on design or recorded L/ESS data. The basic premise of this method, then, is that this relation is not

Figure 5.9. Flight Hour/Landings IAT Method.
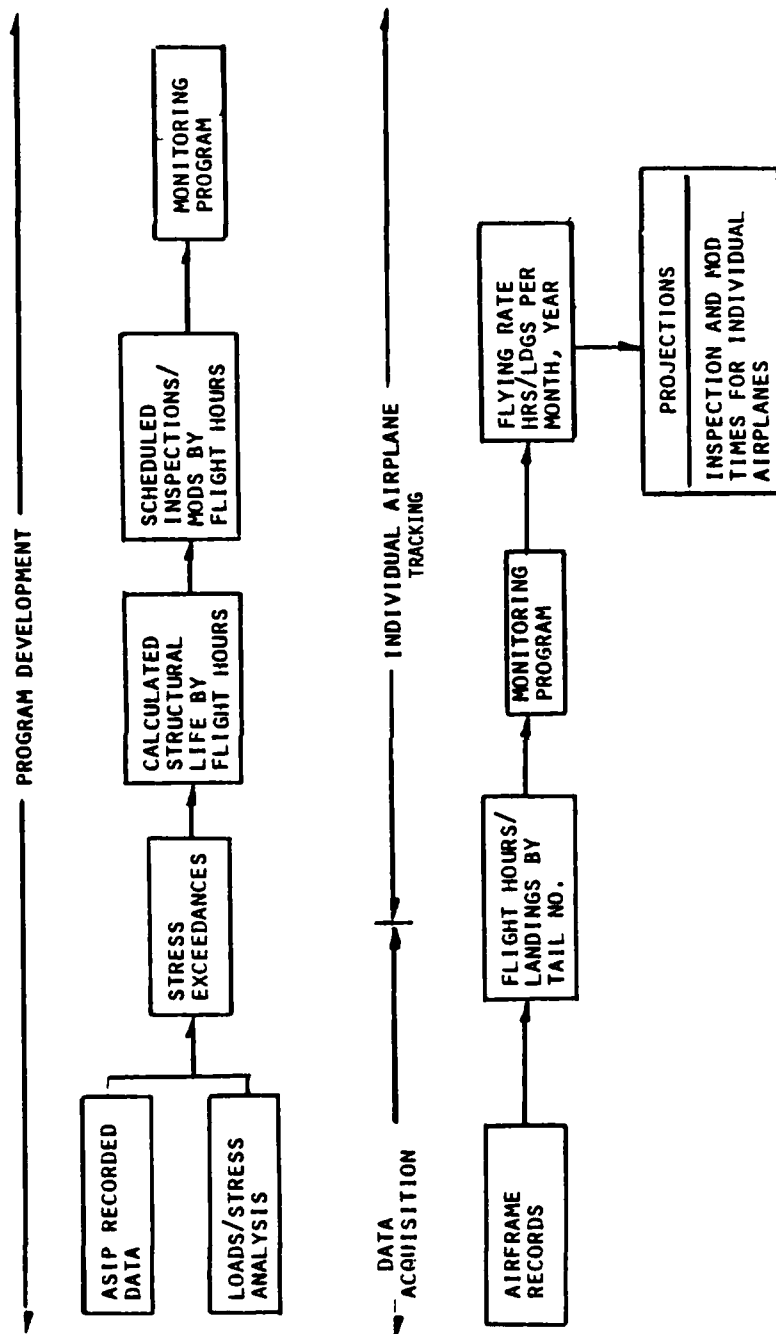
a) Tracking Procedure - METHOD 1

5-34

b) Analysis Scheme - METHOD 1

Figure 5.9. Flight Hour/Landings IAT Method (Concluded).

significantly affected by changes in operations between the individual
aircraft in the force. Thus, all structural planning and scheduling
can be accomplished with sufficient accuracy solely on the basis of
total airframe hours and landings and on the past and current
utilization rate.

Mission Method

This method is based on correlating incremental crack growth
with selected mission categories. A schematic of the method is
presented in Figure 5-10. The mission categories must include
breakdown by mission parameters such as takeoff weight, takeoff fuel
weight, flight purpose, percentage of time in low level, etc.
Between 50 and 500 mission categories would be required to cover
the mission parameters.

An advantage of treating crack growth for an entire flight
is that sequence effects within a mission can be accounted for more
rigorously for "standard" missions. It is not suitable for non-
"standard" sequence, however.

Data Block Method

In the data block method, the information on the usage forms
is used to determine the time spent in data blocks as defined by
combinations of weight, airspeed, altitude, configuration, special
events, etc. The method assumes that the loads within each data
block (whether induced by maneuvers, turbulence, ground, etc) for
prolonged operation of an individual aircraft will eventually
approximate those recorded for the same data block during the
L/ESS. There are two methods of approximating the potential crack
growth.

Figure 5-11 presents a schematic of the
parametric crack growth approach. From a recorded operational data
sample, stress exceedances are derived for each data block and a
sequence of stress cycles is generated in some random fashion. A
crack growth computer program then generates a crack growth rate as
a function of crack length for each data block. These rates become
the parametric crack growth tables. During the operational part
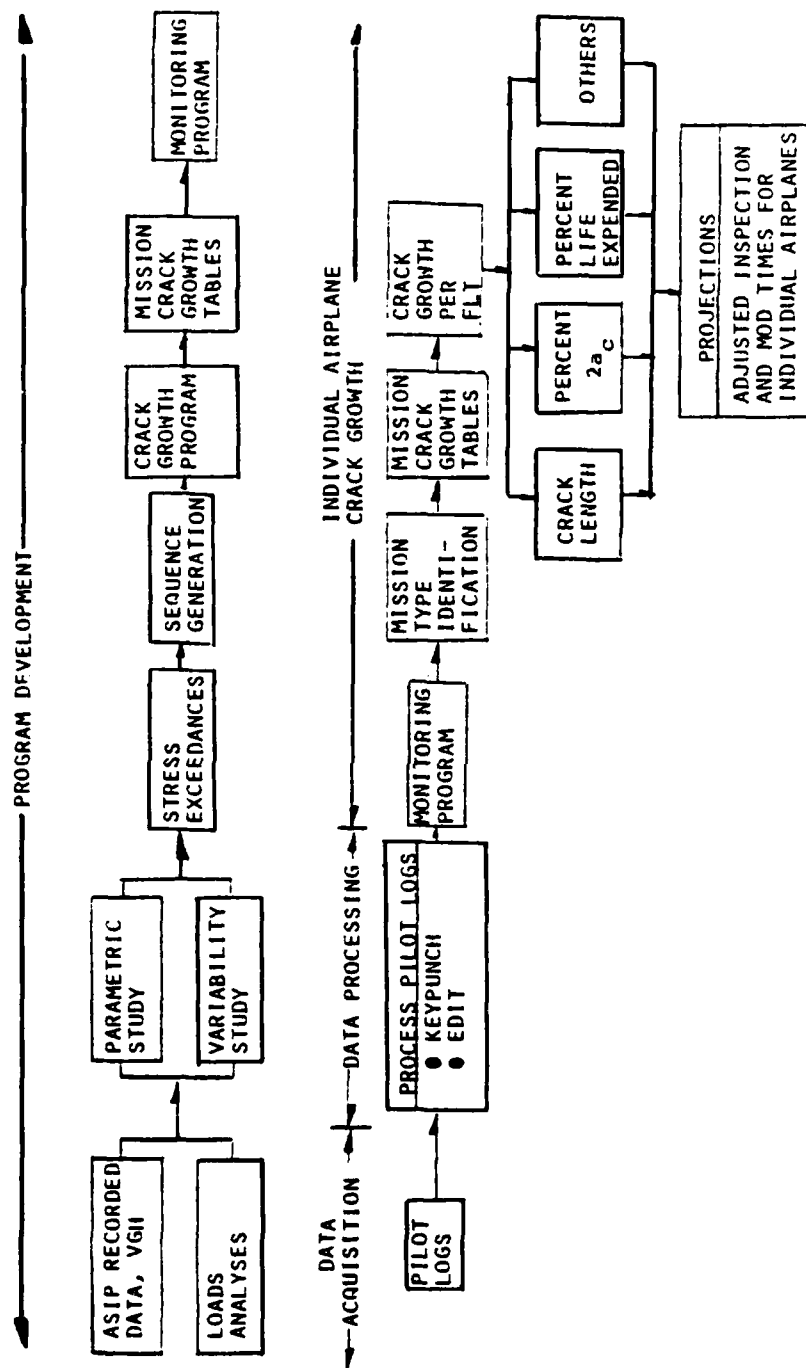
a) Tracking Procedure

Figure 5.10. Mission Method.
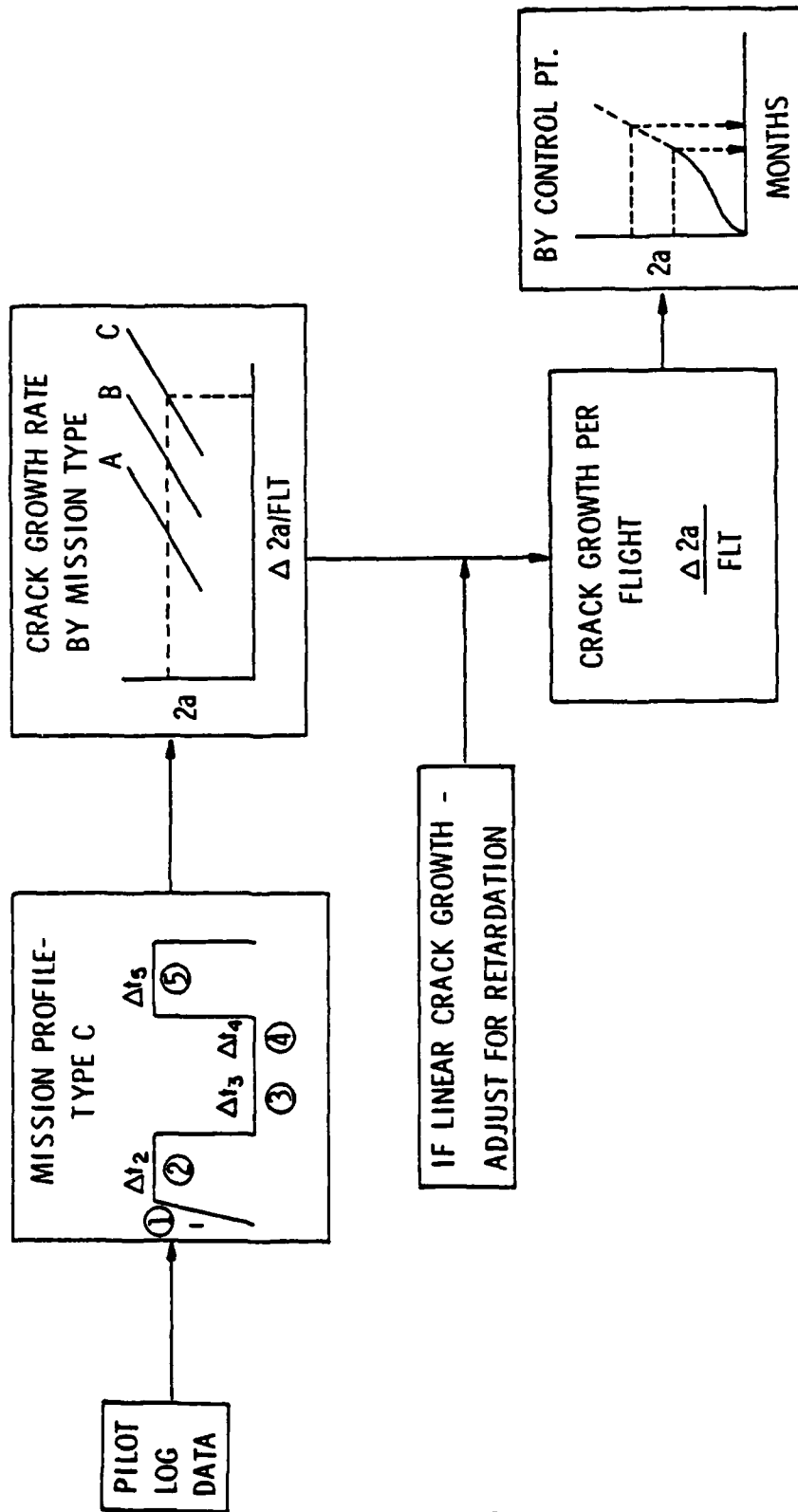
b) Analysis Scheme

Figure 5-10. Mission Method (Concluded).
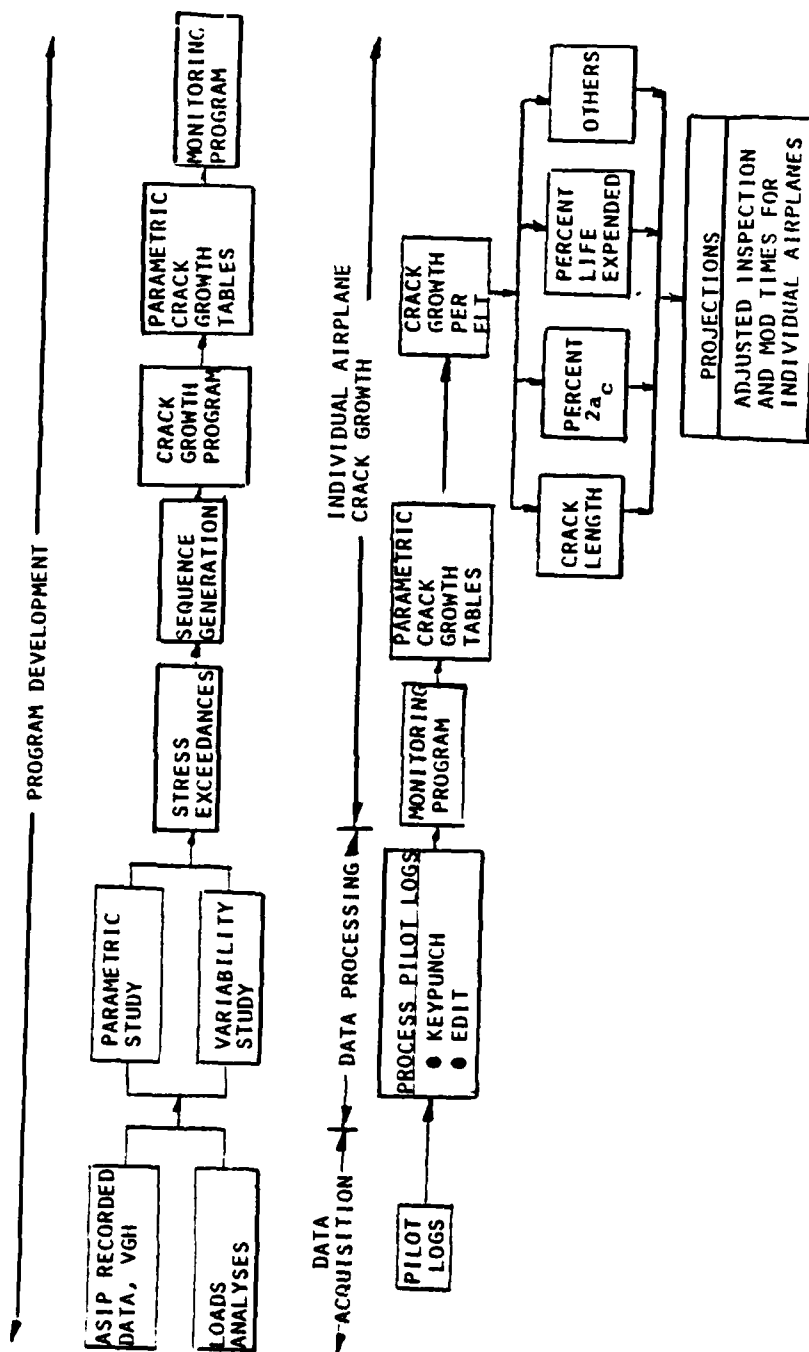
a) Tracking Procedure

Figure 5-11. Data Block Method – Parametric.
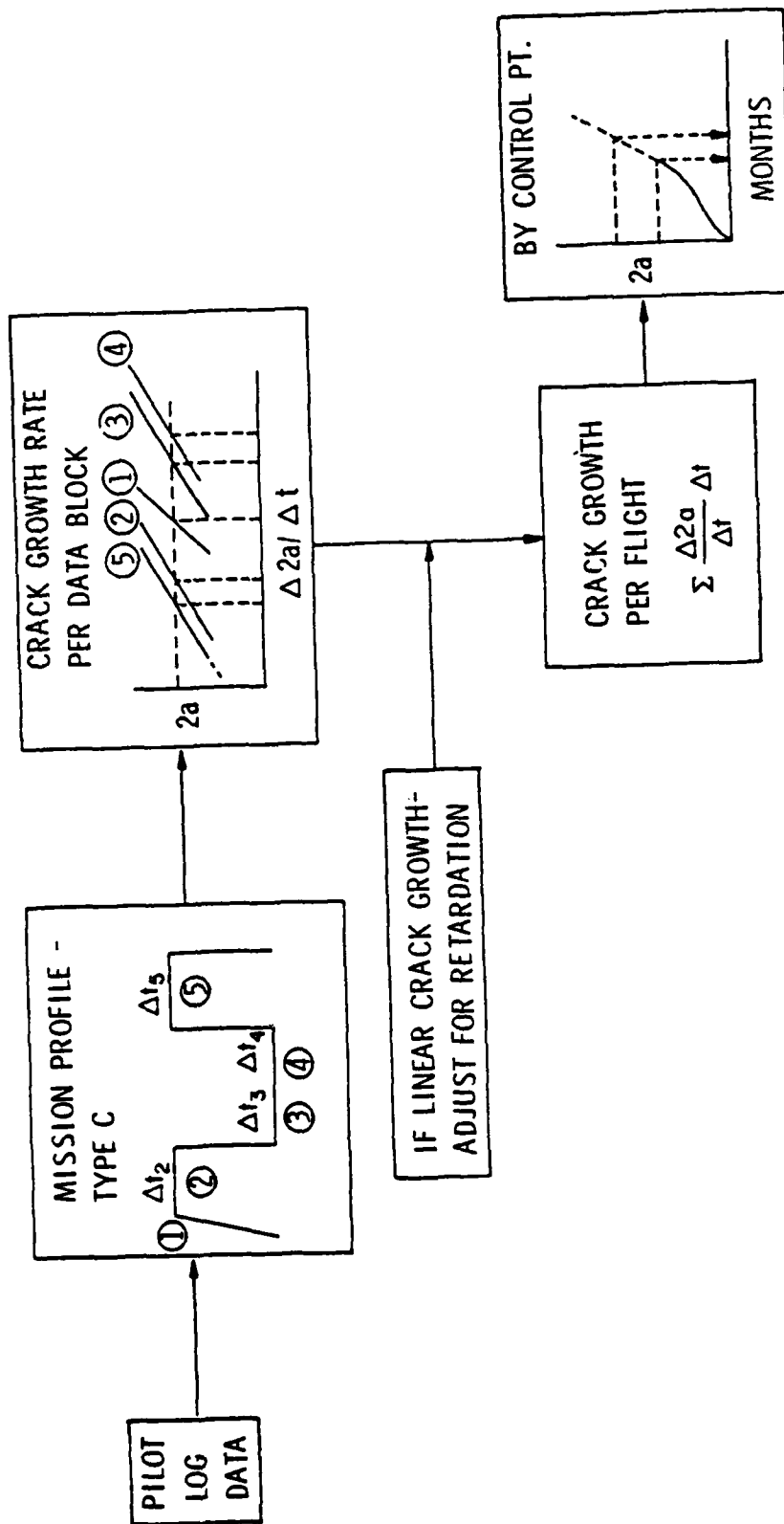
b) Analysis Scheme

Figure 5-11. Data Block Method-Parametric (Concluded).

of this method, the pilot log data is converted to time spent in each data block. The crack growth for each data block is the product of the time and of the crack growth rate (a function of the data block and the crack length at the start of the data block). The retardation effects of loading sequence are either included in the crack growth rates based on typical sequences or are included in the form of an adjustment after specific flight segments.

In the stress occurrence approach, Figure 5-12, stress exceedance curves are generated for each data block (or mission segment) and stored in parametric stress occurrence tables. During IAT operation, the pilot log data is converted to time in each data block. The stress occurrence tables for each data block are adjusted for the time spent and a sequence of stress cycles is generated for the flight by summing the data blocks. Then a cycle-by-cycle crack growth computer program computes the crack growth for the flight based on the crack length at the beginning of the flight. This method allows more flexibility in the sequencing of loads within each flight, but at a significant increase in computer time.

5.2.2.4 Data Collection

During each flight a crew member, probably the flight engineer, makes entries on the crew form at the end of each flight segment, i.e., climb, cruise, low-level, refueling, descent, etc. The contents of the forms vary according to aircraft type, but most will contain aircraft serial number, flight data, a mission type code, mission duration, total aircraft hours, takeoff and landing gross weights and fuel weights, and for each flight segment, the fuel and cargo weights, airspeed, altitude, duration, and any special events such as landing, refueling hookups, airdrops, etc. Following the flight, the completed crew forms are mailed to the System Manager (or to ASIMIS) for computer entries.
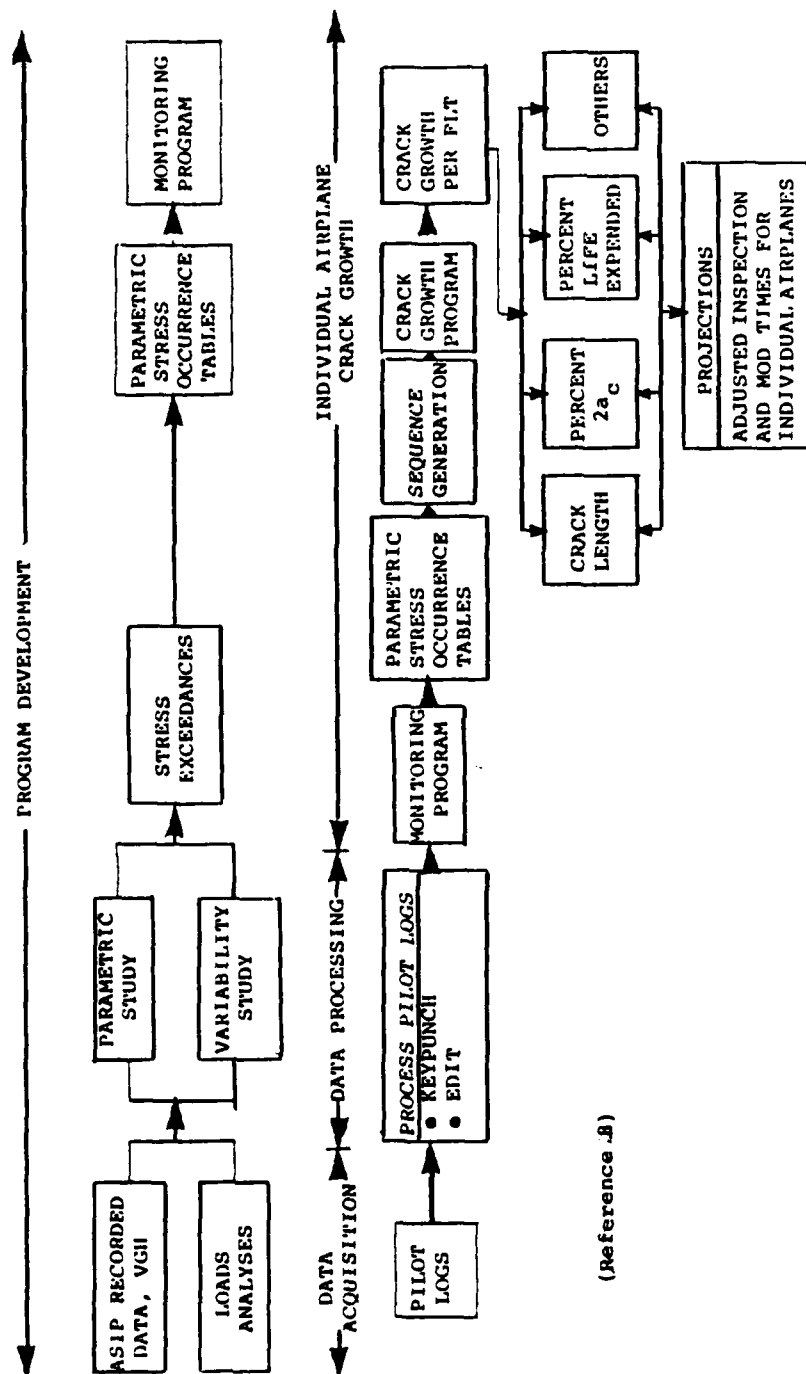
a) Tracking Procedure

Figure 5-12. Data Block Method - Stress Occurrences.
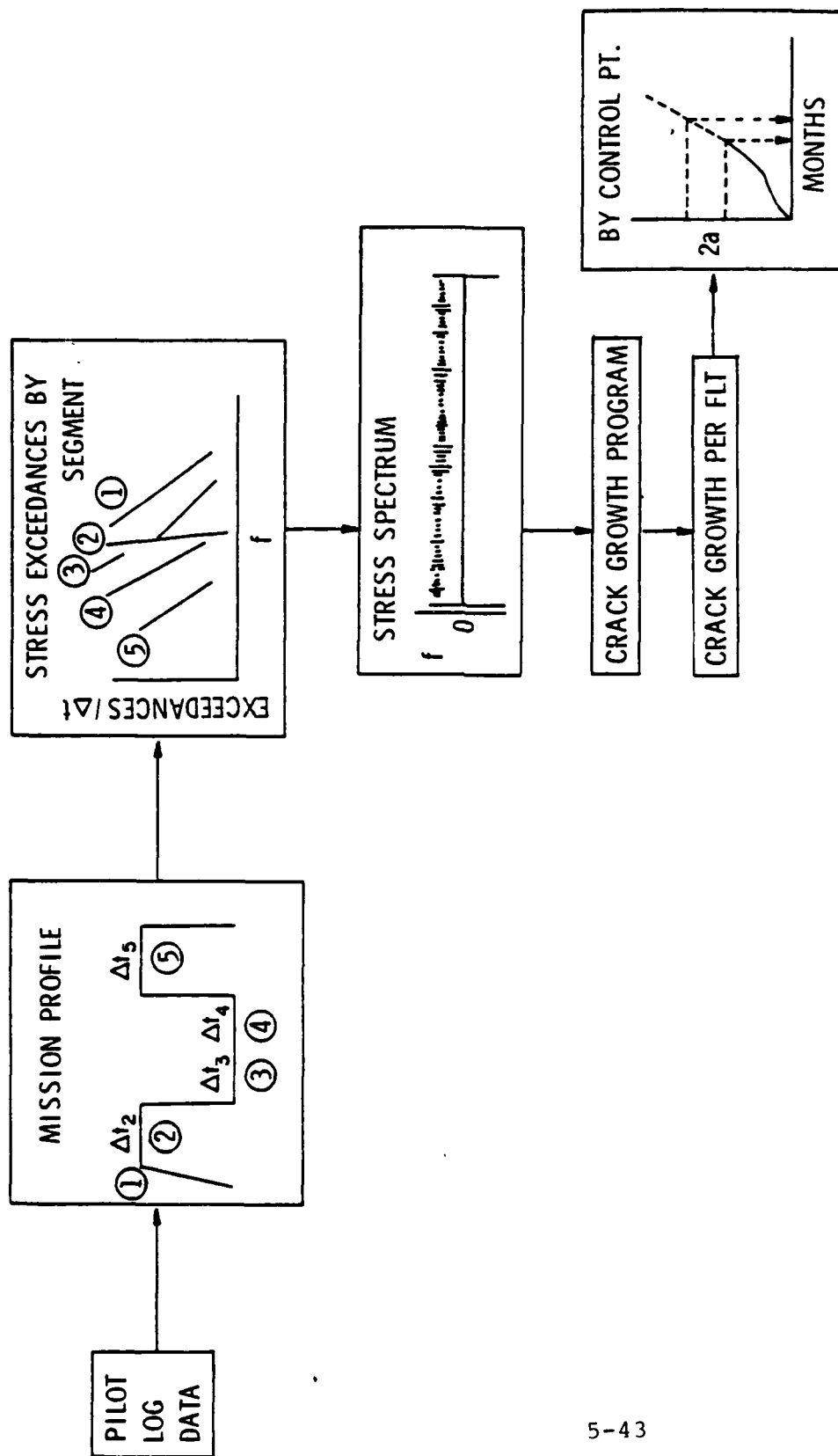
b) Analysis Scheme

Figure 5-12. Data Block Method – Stress Occurrences (Concluded).

While past collection forms have been designed for manual conversion to a computer format, modern form reading equipment dictates that all future forms should be designed for automatic processing. Figure 5-13 is a reproduction of the C-141 reading equipment. This equipment detects pencil marks in specific locations on the page and converts the data directly to a computer formatted tape. The reading equipment has a certain amount of editing capability which detects many types of errors for immediate correction. Errors can be corrected by making a new form with the same tail number, date, and hours and entering only those fields with corrections. The reading equipment then replaces the corrected fields on the data tape.

Special data collection methods are not needed for the flight hours/landing method as this data is recorded as part of the aircraft operations and maintenance records under AFM65-110 Standard Aerospace Vehicle and Inventory, Status, and Utilization Reporting. In particular, aircraft users routinely report flying hours, landings, and flight purpose (mission type) code for each mission flown as logged by the crew on the AFTO Form 781.

5.2.2.5 Data Processing

Problems associated with the processing of usage forms tracking systems are common to all of the analysis methods. The use of optical scanners will efficiently transfer the data from forms to computer, but the problems of verifying and editing the input data remain. To the extent possible, the optical scanning unit should be programmed to provide edit checks and error diagnostics which flag invalid or missing data. Some types of errors can be corrected and missing data supplied internal to the computer. Other data discrepancies will require operator interpretation or follow-up. Given a valid set of raw data, further editing checks may be performed to ensure that mission types or data blocks are consistently defined.

Figure 5-13. AFTO Form 451 (C-141).

5-45

The data processing system is responsible for the application of the gap-filling techniques. In some crack growth based IAT programs, the sequencing of missing flights is considered important. This may consist of computerized sequencing of the mission, determination of gaps via the dates, flight hours and landings data from the usage forms data, and filling in the gaps with flights selected to match pertinent mission descriptions appropriate for the period.

5.2.2.6 Cost Elements

Table 5-10 lists cost elements which may be anticipated for the Usage Forms IAT system. The table is in a common format for use in listing cost elements for the other IAT systems evaluated in this report. The left column lists potential cost elements. A check indicates that this is a cost element of a usage forms tracking system. Words in the right column provide additional information to further describe or scope the cost element for that system.

5.2.2.7 Accuracy

Usage forms tracking is based on the assumption that the stress environment during a data block or mission type can be accurately represented by the average stress environments obtained during the L/ESS program. For any particular flight on which a completed form is available, errors can result from four sources: (a) the sampling error in determining the average environments during the L/ESS; (b) the difference between the assumed stress environment and that actually encountered; (c) inappropriate data block selection and, (d) errors in the recorded data on the pilot log. The sampling error would decrease with quantity of data in the L/ESS. Further, the error would be propagated as a "bias" for any one flight condition but these "biases" could average out when all the flight conditions for a flight are combined. A potentially significant error can result from the selection of data blocks. Data blocks are generally represented by midpoint values. If the blocks are too large and utilization is primarily at one extreme significantly large errors can result. A detailed comparison of

TABLE 5-10

IAT COST ELEMENTS FOR
USAGE FORMS TRACKING

ELEMENTS	USAGE FORMS	COMMENTS FOR USAGE FORMS SYSTEM
INITIAL DESIGN AND DEVELOPMENT OF DATA ACQUISITION DEVICE AND SUPPORTING EQUIPMENT		
DESIGN OF HARDWARE SYSTEM FOR SPECIFIC AIRPLANE		
QUALIFICATION TESTING		
DESIGN OF SOFTWARE SYSTEM FOR SPECIFIC AIRPLANE	X	USAGE FORMS & COMPUTER PROGRAMS
T.O. FOR IMPLEMENTATION	X	
FAB. AND INSTALLATION OF DATA ACQUISITION DEVICE AND SUPPORTING EQUIPMENT (SENSORS)		
REPLACEMENT OF DATA ACQUISITION ELEMENTS: TRANSMITTAL TO ASIMIS	X	USAGE FORMS
SPECIAL READING OF DATA ACQUISITION DEVICE		
DATA TRANSCRIPTION TO MAGNETIC TAPE	X	OPTICAL SCANNER OR KEYPUNCH
COMPUTER ANALYSES OF DATA	X	
GAP-FILLING	X	COMPUTERIZED
SUPPLEMENTARY DATA ACQUISITION; TRANSMITTAL TO ASIMIS		
ADDITIONAL COMPUTER ANALYSES OF SUPPLEMENTARY DATA		
MANUAL CHECKING, ANALYSES, DEBUGGING OF COMPUTER OUTPUT	X	
REPORTS OUTPUT	X	
ON-BOARD SYSTEMS MAINTENANCE		
TEST EQUIPMENT FOR ON-BOARD SYSTEMS MAINTENANCE		

L/ESS data and the IAT data blocks can minimize the effect of such anomalies.

The differences between the assumed and encountered stress environments in a flight condition introduce a random error into the calculation. To date, no data has been published which can be used to measure the magnitude of this random error and, hence, it is not possible to quantify the errors that could result in pilot log trackings. Care will be required in combining the errors from the different flight conditions. Since the incremental crack growth is a weighted average of the potential crack growth during the flight conditions encountered, the variance of the errors in incremental crack growth during a flight will be a weighted average of the variances of the errors in each flight condition.

Errors which result from inaccurate recording of data on the forms (after editing) are non-measurable and probably negligible. Adequate crew training is assumed to assure a conscientious attempt to accurately complete the log. Recording errors which occur can then be assumed to be relatively infrequent, randomly distributed, and inconsequential.

The fourth source of inaccuracies in pilot log tracking results from gap-filling based on aircraft logs. The percent of missing data on current pilot log programs ranges from 0 to 30 percent. In view of the weak correlation between flight hours and baseline hours that can be present in transport/bomber aircraft, this source of error could be quite significant when there is a high percentage of missing data.

Considering the error sources in pilot log tracking, their ranking in decreasing order of importance would be: inaccurate average usage for flight conditions; variability of individual excursions from average conditions; inappropriate data block selection; mission data; and inaccurate recordings on form.

5.2.2.8 Reasonability Factors

Usage Forms IAT programs operate on pre-defined data block mission segment descriptors or pre-defined mission definitions. These definitions are determined through structural engineering utilizing analytic and test data. A computer logic is developed to use input from the usage form entries. Therefore, the IAT program is influenced directly by the reasonability of the forms data; included are such factors as: percentage/return of usable usage forms; forms preparation accuracy; forms data entry recognition of actual/realistic conditions encountered; and, logic interpretation of forms data (gap filling, erroneous data rejection).

Also to be considered in any forms based IAT program is the reasonability by which the computer program operates, calculates and interprets data. This is influenced by: mission/flight descriptor formulation data (i.e. 'points in the sky'); comparision of actual vs. assumed predefined data characteristics (i.e. response/recognition of unusual events); structural analysis methods (damage modules); and output data reasonability.

An IAT Program is a Force Maintenance safety device developed by incorporating engineering analysis, fatigue and static test, flight test and Force Service experience. The program is based on structural analysis which responds to stress level, geometry, fracture toughness, inspectability and safety. The IAT Program should be designed so as to periodically receive updates as needed based on analysis, test and service experience.

5.2.3 Counting Accelerometers

Several types of Air Force aircraft are equipped with counting accelerometers which sense normal accelerations at or near the center-of-gravity, detect peaks in preset acceleration intervals, and accumulate the number of peaks in electro-mechanical counter registers which can be read through windows in the equipment enclosure. The resulting data represents the total number of acceleration peaks during a specific flight or group of flights with no indication of the sequence in which the peaks occurred. Since these accelerations are indicative of the

magnitude of loads being experienced by the aircraft as a result
of pilot induced maneuvers, the acceleration counts provide a natu-
ral indicator of individual aircraft usage severity for attack/
fighter/trainer aircraft. The F-4 and A-7D tracking programs are
used as models for the following discussion.

A counting accelerometer based tracking system is
straight-forward to implement. Periodically, the counts recorded
for the acceleration levels in each airplane are obtained and for-
warded to the central processing location. The data are transferred
to a computer and edited to ensure consistency. The counts for
each airplane are then used in a parametric analysis to obtain an
estimate of the potential crack length. Currently available analyses
estimate potential crack length as a linear function of flight time
and numbers of acceleration peaks at the monitored levels. Further
details of this computation are presented in paragraph 5.2.2.3.
The potential crack length estimates are then summarized and pres-
ented according to the desired data formats.

5.2.3.1 Advantages and Limitations

The principal advantages of the count-
ing accelerometer based tracking system are that it is relatively
simple and inexpensive to apply and its widespread application has
resulted in user personnel familiarity and ease of application. The
center of gravity normal acceleration is a reliable indicator of air-
craft usage severity, particularly for critical locations on the
wings. The transformation of load factor counts to potential crack
growth, however, is dependent on the L/ESS data base for defining
the statistical relationships of load factor to stress to crack
growth. The counting accelerometer is a reasonably reliable device
with no recorder elements to be changed, adjusted, or maintained
on a scheduled basis. The transcription of the data from the recorder
can easily be performed by an airman at essentially no incremental
cost.

The normal acceleration at the center of gravity is primarily limited to the preciseness of its correlation with critical points in the structure. For example, a given load factor in a symmetrical flight condition produces a peak strain state in the reference location, say the wing tension skin. Also produced are corresponding strains in other airplane structure. Thus, there may be many other flight conditions, (ones with the same load factor coupled with unsymmetrical flight conditions) that produce the same counting accelerometer record but an entirely different strain state in the reference location and the remote locations. This is particularly true for tail locations. Even for tail locations, however, it can be assumed that the airplane receiving the largest number of severe maneuvers is also receiving the largest potential crack growth throughout the structure. The precision of potential crack length estimates in the vertical tail may be inadequate.

A second weakness that leads to imprecision in potential crack length estimates is that the counting accelerometer method cannot account for variations in airplane flight conditions. The strains in common critical locations (such as the wing tension skin) are particularly sensitive to the product of the airplane vertical acceleration and the airplane gross weight. Other critical flight parameters may include the instantaneous Mach number (MN), altitude, center of gravity location, and aircraft configuration. The MN effect is due to shifts in the wing center of pressure (CP) that occur as the MN varies. This shift in the CP redistributes the wing load and the resulting strain state. The altitude effect is connected with changes in wing flexibility parameters. Thus, the counting accelerometer is blind to weight, MN, altitude, center of gravity location, and configuration, and dramatic changes in crack growth can be seen with changes in usages and mission parameters.

5.2.3.2 Stress Relationships

The isolation and determination of the transfer of load effects from a reference location to a remote location must be accomplished initially during testing (flight tests, static tests, fatigue tests, damage tolerance tests) of the airplane in question. Data from instrumented tests may be extended and supplemented with analysis (such as the finite element technique) to yield more varied and general solutions. There is little difference in the stress transfer function requirements between the use of various IAT methods for A/F/T aircraft. This is especially true if only one IAT activity indicator is used.

Generally, the critical areas of A/F/T airplanes are concentrated in the wing. However, provision must be made for the case when this is not true. The satisfaction of this requirement demands that statistical methods be developed that will relate loads from one location to another using the IAT activity indicator chosen.

Examples of methods that transfer damage from a reference location to remote locations are direct statistical relationships and "iso-exceedance" relationships. The direct statistical relationship involves deriving equations that express the strain at remote locations as a function of various airplane response parameters. These response parameters should include the tracking variable. A data bank of observations of these parameters along with the associated strain can be generated during flight test operations or may be derived analytically. These observations may then be used to obtain expressions for the transfer of strain.

The iso-exceedance method involves relating variables by virtue of the number of times they exceed certain values. The method provides a statistical relationship between parameters whose peaks do not occur simultaneously or in cases where there is no basis for the existence of a direct functional relationship. An example of an iso-exceedance relationship, taken

from an A-7D study, is shown in Figure 5-14. Here the stress in the airplane's horizontal tail is related to the vertical load factor at the center of gravity. There is, or can be, an influence between the tail load and the load factor, but there is no direct relationship available as the peaks of the two parameters occur at different times. However, a relation is established if the data is observed on an "equal exceedance" or iso-exceedance basis. That is, the stress at a certain level occurs with the same frequency as a selected load factor level. The data can be cross-plotted to reveal a relatively simple empirical relationship. This relationship was established using flight data points, not analysis.

5.2.3.3 Crack Growth Model/Example

A general n_z exceedance normalized crack growth IAT method is summarized in Figure 5-15. This method is basically that of both the F-4 and A-7D aircraft. The input data required by the model are the aircraft flying hours and the reported exceedances of the vertical load factor at four preset levels. The method of Figure 5-15 is based on relatively long intervals between data recordings. In an effort to obtain a closer correlation between load factor and stress levels, systems are being considered which will require weight, stores and configuration information to be associated with load factor counts during each flight. The analysis methods for using these data in a crack growth based IAT have not yet been developed.

In general, the methods of IAT are based upon the ability to experimentally and analytically grow cracks in a structure given known stress spectra. However, measuring the n_z counts on each individual aircraft and relating this to stress and finally growing the crack for each individual aircraft would be economically prohibitive. The measured IAT data must be related as closely as possible in some manner to a previously grown crack for determining the predicted crack growth for each individual aircraft. For every crack grown experimentally or analytically, there is a corresponding known spectrum of the n_z
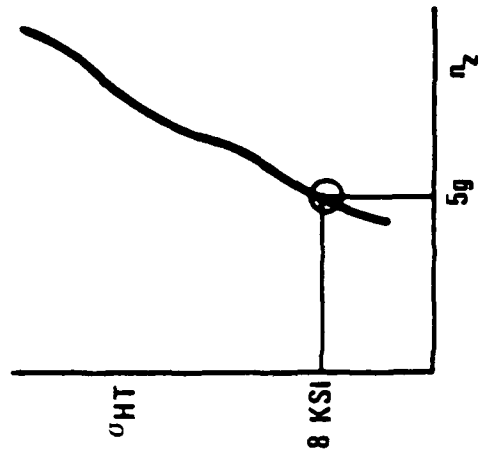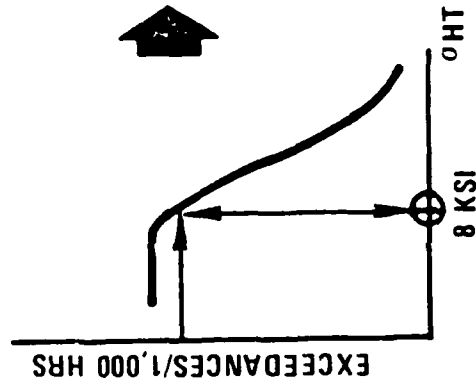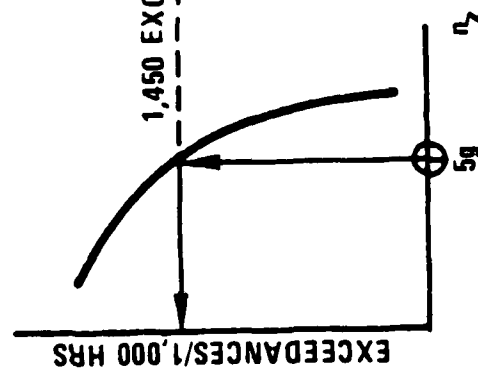
Figure 5-14. Relating Tail Spectra to Normal Load Factor Spectra.
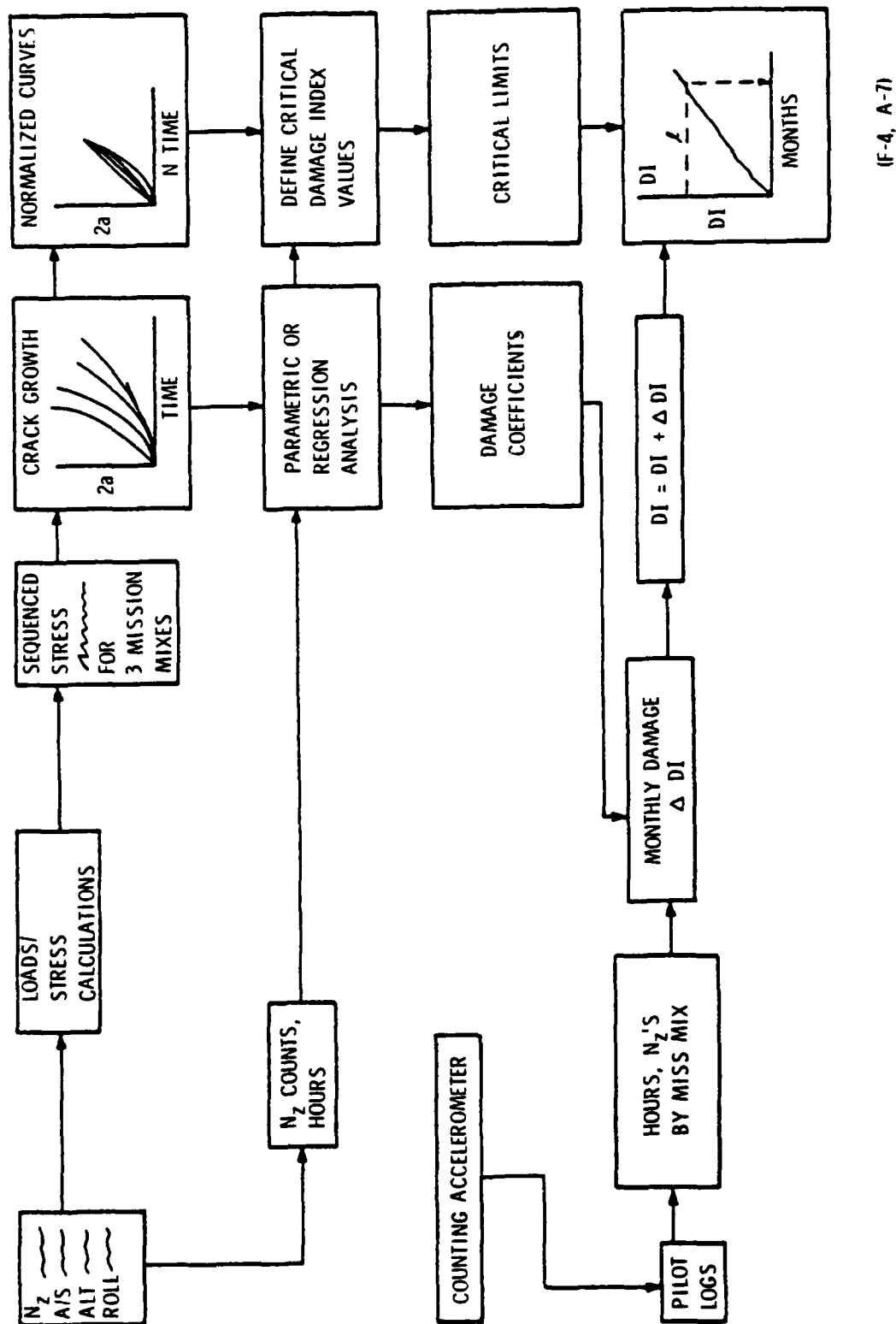
b) Analysis Scheme

Figure 5-15. Normalized N_z Exceedance Crack Growth (Concluded).
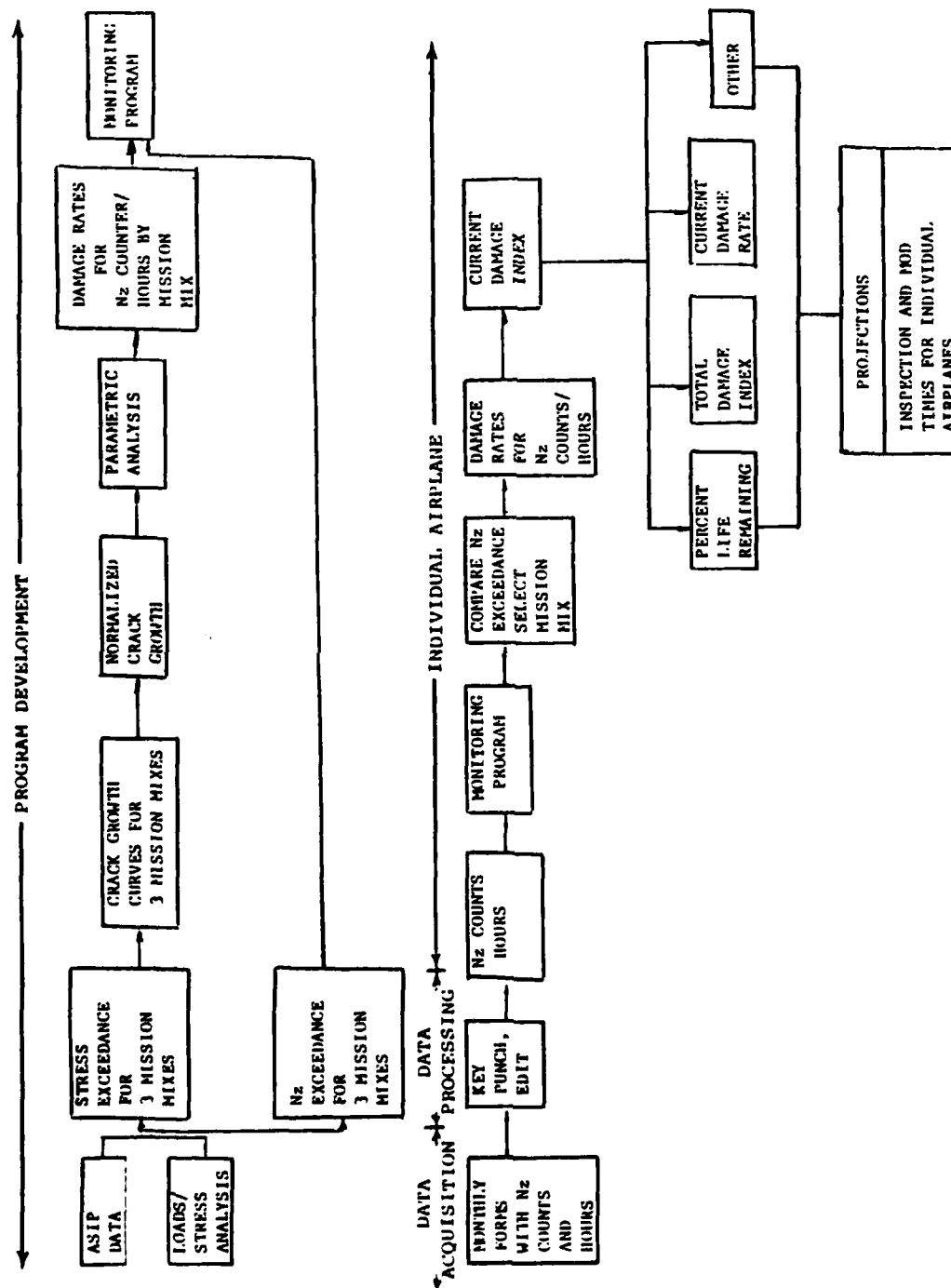
Figure 5-15. Normalized N_z Exceedance Crack Growth.

a) Tracking Procedure

counts thus providing the relationships to go from measured n_z counts to crack growth.

For this analysis method, there are two basic assumptions: 1) Crack growth at one location can be correlated with crack growth at a different location through the use of normalized crack growth curves based upon the ratio of the operational limits of the two locations, and 2) Crack growth at a location due to a particular usage spectrum can be correlated with the crack growth for a different usage spectrum through the use of normalized crack growth curves based upon the ratio of the operational limits of the two spectra. These relationships are demonstrated in Figure 5-16 where the operational limits are designated by t_{A_O}, t_{B_O}, t_{1_O}, and t_{2_O}. The spread or scatter shown in the normalized curves represents the envelope of all structural locations and all usage spectra, thus they can be represented by a single curve with very little error.

Hence, these assumed relationships allow tracking only one location on each aircraft as well as accounting for spectra variations from the baseline spectra (tested spectra). The relationship between damage at the monitoring location and damage at another location is only valid if the spectra at the two locations are both based on the same activity indicator. For the F-4 and A-7, the spectra for the critical locations on the fuselage and wing are all based on n_z, therefore, these relationships hold. However, for more recent generation of A/F/T aircraft, which have more sophisticated control systems such as differential tail augmented roll, variable sweep wings, etc., more than one activity indicator and more than one monitored location may be required.

For a matter of convenience, the F-4 and A-7 tracking programs use an arbitrary "damage index" (D.I.) system instead of hours to specify when maintenance actions are required. Referring to the bottom right hand graph of Figure 5-16 and letting the Spectrum #1 be the baseline spectrum, then the normalized abscissa is scaled by a chosen constant (DI_{BL_O}), which is the D.I. that occurs when the baseline spectrum reaches the

5-57
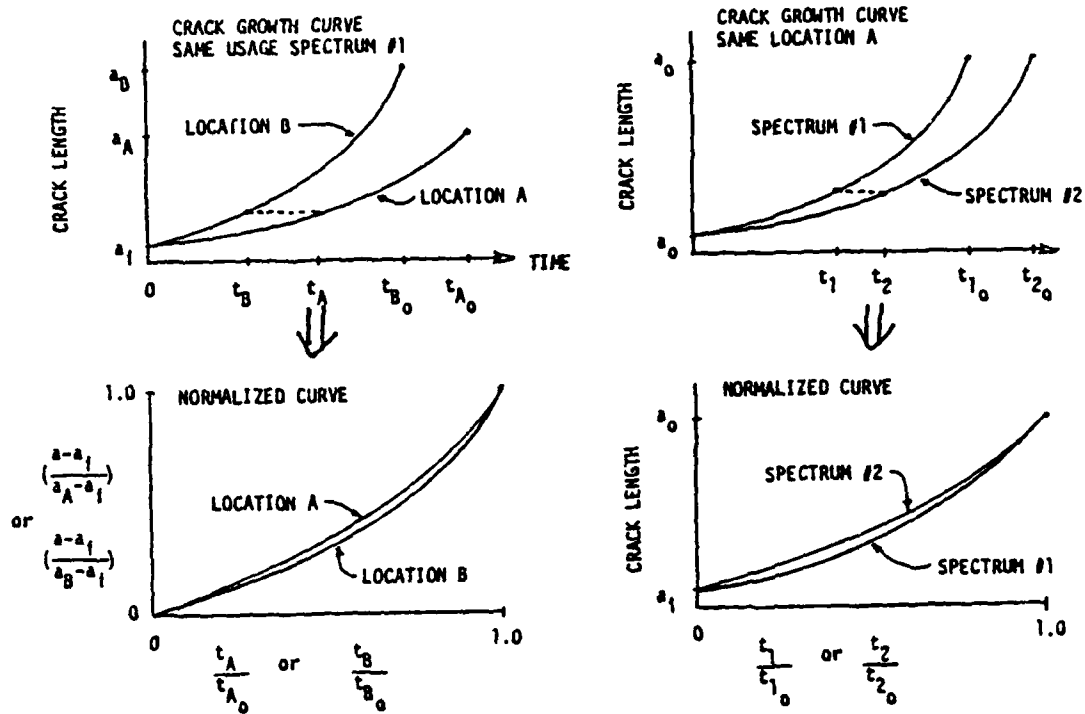
Figure 5-16.   Normalized Crack Growth Curves.

operational limit at the monitored location. For example, if at the operational limit of the baseline spectra (t_{1_O}) a damage index value is assigned to be D.I. = 4.0, then the normalized crack growth curve can be redrawn in terms of D.I. as shown in Figure 5-17. If t_{1_O} was the safety limit for the monitored point, then for an aircraft flying Spectrum #2 there would be a requirement to inspect at one-half the safety limit, or at a D.I. of 2.0, which corresponds to Spectrum #2 flying hours of

$$t_2 = \frac{2(t_{2_O})}{DI_{BL_O}} = \frac{2(t_{2_O})}{4} = 1/2(t_{2_O})$$

It may be found that another location (B) in the aircraft is more critical and will have to be inspected at a D.I. of 2.0 (t_{B_O}/T_{A_O}). The term (t_{B_O}/t_{A_O}) is the ratio of the operational limits of location B to monitored location A.

The methods of determining the damage index (D.I.) for an individual aircraft for the F-4 and the A-7 are similar. Both methods assume a linear relationship between D.I. and the measured activity indicator, n_z. In the case of the A-7, flying hours take part in the relationship as well. These are as follows:

F-4 $D.I. = C_1 X_1 + C_2 X_2 + C_3 X_3 + C_4 X_4$

A-7 $D.I. = C_O T + C_1 X_1 + C_2 X_2 + C_3 X_3 + C_4 X_4$

where

    D.I. is damage index for a time period

    C_O, C_1, C_2, C_3, C_4 are coefficients (constants)

    T is flying hours for the time period

    X_1, X_2, X_3, X_4 are the n_z occurrences or exceedances
        of the four level counters during time period T
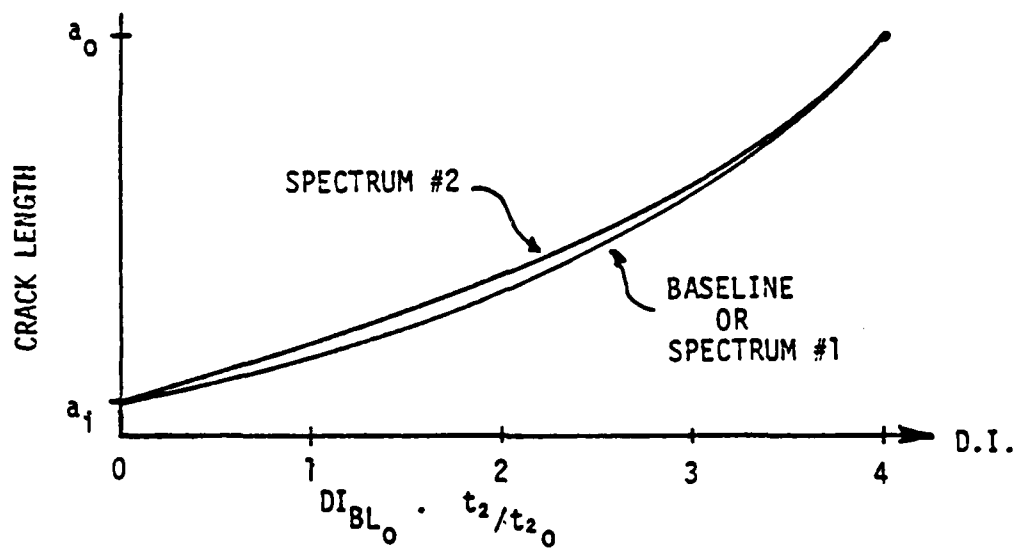
Figure 5-17.   Crack Growth Curve Normalized to Damage Index.
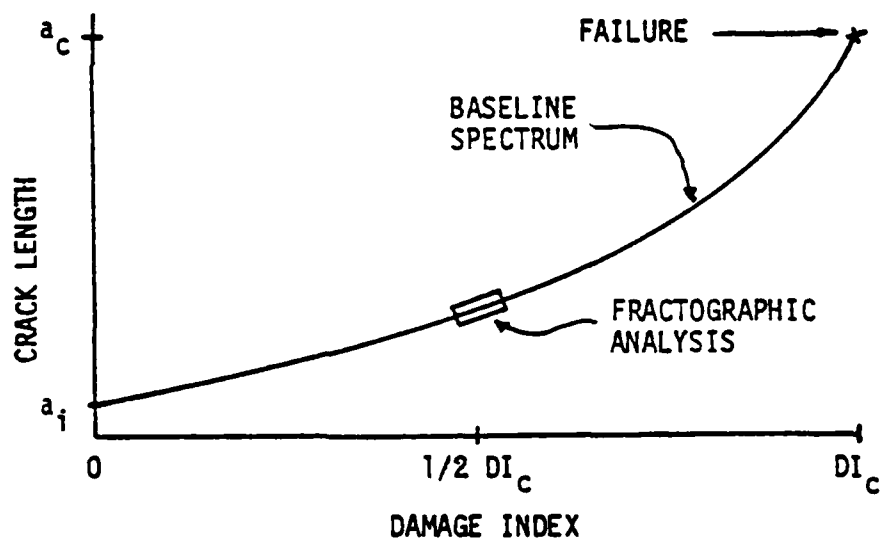
Figure 5-18.   Baseline Crack Growth Curve.

It is noted that the counting accelerometer counts exceedances (E) of four levels of n_z, so in the case of the A-7, $X_1 = E_1$, $X_2 = E_2$, $X_3 = E_3$, and $X_4 = E_4$. The F-4 technique uses occurrences of load factor peaks, which mathematically makes no difference, thus: $X_1 = E_1 - E_2$, $X_2 = E_2 - E_3$, $X_3 = E_3 - E_4$, and $X_4 = E_4$.

The F-4 and A-7 methods of calculating damage differ in the methods by which the coefficients in the D.I. equations are calculated. Basically, they are derived from results of cracks grown to different spectra in coupons representing the monitored location.

For the F-4, pre-cracked fracture specimens simulating the monitored location were cycled to failure (safety limit) for each of three usage spectra defined as baseline, severe, mild. For example, the resulting crack growth curve of the monitored location for the baseline spectra is illustrated in Figure 5-18. Known at the time of failure are the total number of occurrences of each of four levels of n_z (i.e., X_1, X_2, X_3, X_4). Also known is the fracture limit, in terms of damage index (i.e., $DI_c = DI_{BLo}$). Thus, for this spectrum, all of the parts of the damage index equation are known except the coefficients C_1, C_2, C_3, C_4.

$$DI = C_1 X_1 + C_2 X_2 + C_3 X_3 + C_4 X_4 .$$

It is assumed that the total DI_c is spread over the four levels measured by the counters. Thus,

$$DI_c = W_1 (DI_c) + W_2 (DI_c) + W_3 (DI_c) + W_4 (DI_c)$$

where $W_1 \ldots W_4$ represent weighting functions giving the relative contribution of each n_z level to the total DI_c, with

$$W_1 + W_2 + W_3 + W_4 = 1.0$$

$$W_1 (DI_c) = C_1 X_1 , \ldots , W_4 (DI_c) = C_4 X_4$$

and finally:

$$C_1 = \frac{W_1(DI_C)}{X_1} \qquad\qquad C_2 = \frac{W_2(DI_C)}{X_2}$$

$$C_3 = \frac{D_3(DI_C)}{X_3} \qquad\qquad C_4 = \frac{W_4(DI_C)}{X_4}$$

After failure of the specimen, scanning electron microscope traces were obtained of a 2100 hour portion of the fracture surface at approximately one-half the fracture limit (i.e., $DI_C/2.0$). (See Figure 5-18). Individual striations of crack growth were then measured corresponding to each load level in the spectrum. Then by relating load level to the four n_z levels, the relative percentage (i.e., W_1, W_2, W_3, W_4) of crack growth caused by each n_z level was calculated. For example, in the case of the baseline spectrum:

$$W_1 = .075, W_2 = .135, W_3 = .28, W_4 = .51$$

Using these relative weights with the known X_1, X_2, X_3, X_4, and DI_C, the coefficients are solved. This solution is plotted in the form of an equivalent S-N curve through the stress levels corresponding to the four n_z levels.

The same procedure is followed in testing the other two specimens to the mild and severe spectra. The same damage index (DI_C) at the fracture limit is used along with different occurrences (X's). Fractographic analysis of each specimen presents new weighting functions (W's). Consequently, coefficients $C_1 \ldots C_4$ and the equivalent S-N curve are determined for each of the three usage spectra. Rewriting the original F-4 damage index equation for the three usage spectra gives:

Mild: $DI = C_{1_M} X_1 + C_{2_M} X_2 + C_{3_M} + X_3 + C_{4_M} X_4$

Baseline: $DI = C_{1_B} X_1 + C_{2_B} + C_{3_B} X_3 + C_{4_B} X_4$

Severe: $DI = C_{1_S} X_1 + C_{2_S} X_2 + C_{3_S} X_3 + C_{4_S} X_4$

During the IAT program, these equations are used to calculate the damage index of an individual F-4 airplane, depending upon which usage spectrum best describes the actual usage of the aircraft for the particular time period T. The choice of equation is established by magnitude of the exceedances of the third level counter (E_3) normalized to the period flying hours, T. This is presently determined as follows:

IF	-Then-	USE THE USAGE SPECTRA
E_3/T is less than 1.1		Mild
E_3/T is between 1.1 and 2.2		Baseline
E_3/T is greater than 2.2		Severe

Once the D.I. is calculated for this time period T, then this D.I. is added to the accumulated damage index for all hours preceding this time period to obtain the present D.I. for that particular F-4 aircraft.

To determine the coefficients in the damage equation for the A-7, eight preflawed specimens representing the monitored location were tested to different usage spectra. Wide variations in spectra were used to represent the envelope of operational usage. Using a combination of test results and crack growth models, cracks were grown for each spectrum to a critical crack size, a_c, that corresponds to the fracture limit, identified in Figure 5-19. Known at the fracture limit are the flying hours (T) and the total number of exceedances of each of four levels of n_z (i.e., X_1, X_2, X_3, X_4) that correspond to the eight spectra. Each
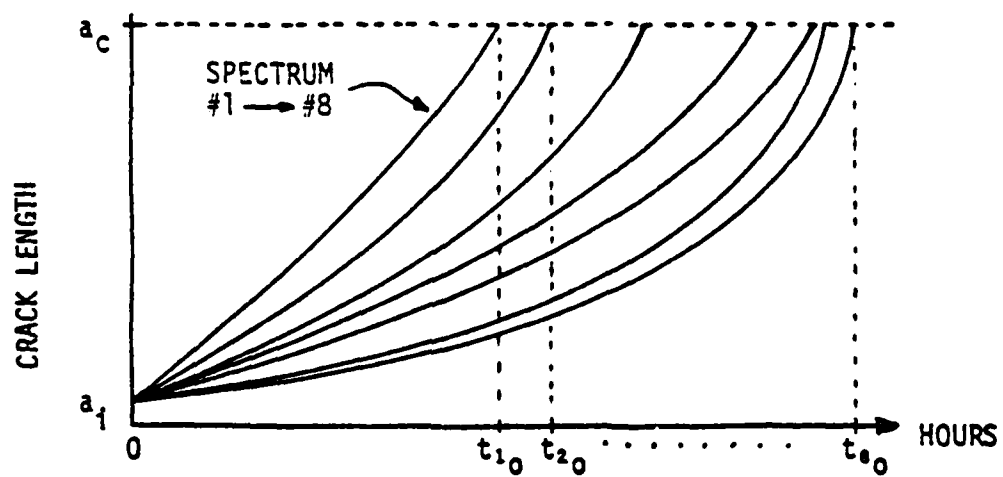
Figure 5-19. Spectrum Crack Growth Curves.

curve has the same damage index at the fracture limit (i.e.: DI_{BL_0}).
Therefore, there is a regression equation of the form

$$DI = C_oT + C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4$$

with many observations of the independent variables T, X_1, X_2, X_3, X_4. The coefficients C_0, C_1, C_2, C_3, C_4 are derived by use of regression analysis techniques where the resulting values give the least sum of squares error. During the IAT program, total flying hours and the total exceedances of each of the four n_z levels are reported on an individual A-7 airplane. These data, representing the entire past history of the aircraft, are used in the above equation to calculate the current damage index.

5.2.3.4   Data Collection

To minimize the extent of the field support required for data retrieval on F-4 and A-7 aircraft, a mechanic is required to visit the aircraft once a month, to gain access to the indicator, and to write down on a simple form the aircraft tail number, the date of data retrieval, the base, the current aircraft hours, and the current contents of each counter window. A single form, such as the AFTO Form 109 in Figure 5-20 records the monthly data retrieval from as many as twenty (20) F-4 aircraft. The completed monthly forms are mailed to the System Manager (or to ASIMIS) for keypunching. Local records for the counting accelerometer on each F-4 are maintained on an AFTO Form 101, shown in Figure 5-21, which is designed to provide a monthly check of the data for unusually high or low counts in any window. Detection of problems at base level is much more effective than waiting for the data processing checks to locate probable malfunctions.

In case of a problem, the base level mechanic can remove and replace either the accelerometer transducer or the indicator. The removed units can be checked for calibration using a standard rate table available in most instrument shops. Malfunctioning units are sent to the Item Manager for replacement and repair.

Figure 5-20. AFTO Form 109.

Figure 5-21. AFTO Form 101.

For certain A/F/T aircraft types equipped with counting accelerometers, it was decided that the accelerations must be associated with takeoff weight and stores and with the mission types for accurate estimation of damage or crack growth. To make this correlation, the counting accelerometers are read after each flight and the counts are written along with the mission information on new forms, as follows with the F-15 program serving as an example. The pilot, or another crew member, is required to enter the aircraft tail number, base, date, mission type, code, takeoff weight, the number of events (such as refuelings and landings), the flight duration, and the total aircraft hours on a special form after each flight. Following each flight, a mechanic is required to go to the aircraft, gain access to the indicator, and to enter the readings from the counter windows on the crew form. The crew forms are mailed to the System Manager (or to ASIMIS) for entry into the computer for the IAT analysis. Figure 5-22 presents the F-15 data form which is compatible with an optical scanning unit. All such future forms should be designed to be read optically.

5.2.3.5 Data Processing

The processing of counting accelerometer data to estimate potential crack length is straightforward and requires only the usual care in the handling and editing of data. Checks should be built into the software system to identify missing or erroneous data at the soonest possible time in the data processing flow. Due to the four digit nature of the acceleration counters, counts from the previous time period should be maintained to identify when the four digit registers turn over. In the absence of direct information on malfunctioning instruments, plausibility checks should be performed on the final crack growth increments. Gap-filling is performed from the average or planned usage of the FSM plan.

Figure 5-22. AFTO Form 239 (F-15).

5.2.3.6 Cost Elements

The cost elements which may be anticipated in a counting accelerometer based tracking system are presented in Table 5-11. The table is in a common format for use in listing cost elements for other IAT systems. Potential cost elements are listed in the left-hand column. A check indicates the applicability of the cost element to a counting accelerometer based system.

5.2.3.7 Accuracy

It is not possible to quantify the accuracy of a counting accelerometer based tracking system. Potential errors depend on both the relationship between normal load factors and stress at the critical point as well as the efficacy of the technique for correlating the usage parameter with potential crack growth.

Normal acceleration is fairly well correlated with wing stresses in A/F/T aircraft but other parameters must be included for a more accurate stress prediction. In deriving the relationship between n_z level crossings and crack growth, all other parameters are ignored under the assumption that their values are representative of force usage. If operational usage changes significantly, the correlation between n_z and crack growth could also change significantly and the correlation equations between n_z and crack growth would need to be modified. In particular, the next most important parameters for calculating stress would be the mission parameters of aircraft weight and configuration. To minimize this error source, the accelerometer counts could be recorded after each flight and submitted with mission data which describe weight and configuration. Although this approach has been used in tracking systems based on Miner's damage, no crack growth based system has been made operational using flight-by-flight accelerometer recordings. The added requirement of a form (accurately completed) for each flight could lead to a high percentage of missing data and, hence, more inaccuracy due to gap-filling.

TABLE 5-11

IAT COST ELEMENTS FOR
COUNTING ACCELEROMETER TRACKING

ELEMENTS	CA	COMMENTS FOR COUNTING ACCELEROMETER SYSTEM
INITIAL DESIGN AND DEVELOPMENT OF DATA ACQUISITION DEVICE AND SUPPORTING EQUIPMENT		COMPLETED
DESIGN OF HARDWARE SYSTEM FOR SPECIFIC AIRPLANE	X	
QUALIFICATION TESTING		COMPLETED
DESIGN OF SOFTWARE SYSTEM FOR SPECIFIC AIRPLANE	X	
T.O. FOR IMPLEMENTATION	X	
FAB. AND INSTALLATION OF DATA ACQUISITION DEVICE AND SUPPORTING EQUIPMENT (SENSORS)	X	
REPLACEMENT OF DATA ACQUISITION ELEMENTS: TRANSMITTAL TO ASIMIS	X	FORMS
SPECIAL READING OF DATA ACQUISITION DEVICE		
DATA TRANSCRIPTION TO MAGNETIC TAPE	X	OPTICAL SCANNER OR KEYPUNCH
COMPUTER ANALYSES OF DATA	X	
GAP-FILLING	X	COMPUTERIZED
SUPPLEMENTARY DATA ACQUISITION; TRANSMITTAL TO ASIMIS	X	POSSIBLE FUTURE SYSTEM
ADDITIONAL COMPUTER ANALYSES OF SUPPLEMENTARY DATA	X	POSSIBLE FUTURE SYSTEM
MANUAL CHECKING, ANALYSES, DEBUGGING OF COMPUTER OUTPUT	X	
REPORTS OUTPUT	X	
ON-BOARD SYSTEMS MAINTENANCE	X	IF NECESSARY
TEST EQUIPMENT FOR ON-BOARD SYSTEMS MAINTENANCE		

On the other hand, the constant recording of accelerometer counts could lead to quicker detection of counting accelerometer malfunctions. The effects of this trade-off are unknown in general. However, the A-7 IAT program is based on monthly readings of the counting accelerometers and reports a data capture rate of 70%. The A-10 IAT program requires flight-by-flight recordings and reports a capture rate of 90%. The causes of the missing data would have to be investigated before a general conclusion regarding missing data from the two approaches could be formulated.

5.2.4 Mechanical Strain Recorders

Strain measurements at critical control points in the structure have the potential of providing the most accurate tracking system. If the strain measurements are made via electrical resistance gages, an electrical signal recorder is required and this form of recording is discussed under the microprocessor-based IAT systems. The mechanical strain recorder (MSR) is a self contained unit which provides a direct sequenced trace of the total strain experience at a specific structural location. Therefore, one or more MSR's on each aircraft provide a sound basis for a tracking program. However, as previously noted, strain history data at a few locations are considered to be insufficient data for a tracking program in transport/bomber aircraft. Thus, the MSR is considered primarily for application in attack/fighter/trainer aircraft. (Current MSR devices could be modified to be sensitive to the stress ranges of transport/bomber aircraft and could be used for tracking particular locations in this aircraft class.)

5.2.4.1 Advantages and Limitations

The mechanical strain recorder is a simple, light weight device which does not require any external mechanical or electrical power. It does not require any input from the flight crew and only minimum ground crew maintenance. It lessens the dependence on analytical models and gives a history of the strain cycles in sequence. Thus, the MSR is a usage severity indicator that is independent of the definition of flight condition at the location at which the stress is being monitored.

The limitations of the MSR are imposed by the need to transfer stresses to critical locations of interest and the increased complexity of the data handling processes for stress measurements. The stress transfer problem can be alleviated by the use of multiple MSR's on each aircraft to monitor different structural areas. It is doubtful, however, that the stress traces from different MSR's can be correlated to allow accurate stress transfer to intermediate locations. In addition, for Transport/Bomber aircraft which respond to low amplitude loads, the threshold level of the MSR may be a problem.

5.2.4.2 Stress Relationships

The methods of transferring load effects from a reference location to remote locations are not specific to the MSR activity indicators. The discussion of paragraph 5.2.3.2 applies equally well to the MSR if only one recorder is used. Theoretically, more accurate stress transfer could be achieved if multiple recorders at well placed locations are used. However, the practical problem of correlating stress peaks and valleys from recorders at different locations precludes this possibility.

5.2.4.3 Crack Growth Models/Examples

The data from an MSR can be reduced to a sequence of stress peaks and valleys at the attachment location of the structure. These basic data can be input to two types of crack growth models. First, the observed sequence of stress peaks and valleys can be transformed to the critical locations of interest and input directly into standard crack growth models. See Reference 5-9 for details. The second method is to reduce the stress histories to numbers of exceedances of defined stress levels and correlate the exceedances with crack growth parametrically (in a manner much like the counting accelerometer approach, paragraph 5.2.3.3).

The cycle-by-cycle approach has the potential to be an accurate tracking method depending primarily on the accuracy of the stress transfer. The cycle-by-cycle approach could also require a large amount of computer time if the IAT system was designed to perform many stress transfers and crack growth calculations for many control points of a large force. The potential computer problem could be alleviated by a hybrid cycle-by-cycle - parametric approach in which potential crack growth is calculated cycle-by-cycle at one control location and transferred parametrically to other locations as in paragraph 5.2.3.3.

In the parametric approach which depends on the correlation of stress exceedance counts and crack growth, the methods of paragraph 5.2.2.3 are directly applicable and will not be repeated. A somewhat different approach was developed for application to the F-16 force and is described in the following paragraphs.

The normalized stress exceedance crack growth method for the F-16 IAT is shown in Figure 5.23. The predicted crack lengths for every critical location in the airframe are calculated. This method is not dependent upon the assumptions required for the previously described F-4 and A-7 methods pertaining to the "normalization" of the crack growth between different locations and the "normalization" of the crack growth from different spectra. The F-16 activity indicator is measured strain at a location that is predominately sensitive to vertical wing bending.

Crack growth curves are computed for each critical location for each of five usage spectra. These are computed using both analytical models and coupon test results. For each critical point, these crack growth curves can be described as illustrated in Figure 5.24. The five variations of the usage spectra are chosen to span the range from the least severe to the most severe expected usage. Corresponding to each of these usage spectra is a spectrum of the activity indicator (strain) at the monitored location. These strain spectra at the monitored location are expressed as normalized exceedances of a derived strain function $f(\sigma)$ and appear as shown in Figure 5-25.

If MSR data is gathered on a particular airplane for a time period Δt, and the strain is expressed in the same normalized exceedance manner, then it may appear as the dashed line in Figure 5-25. Through the use of interpolation methods, this aircraft's usage spectra can be related back to an interpolated crack growth curve (now normalized) for each critical point as shown in Figure 5-26. The crack length (a_b) at the beginning of the period is used to find the time at t_{N_b}, to which is added the normalized time period (Δt_N), arriving at time t_{N_e} at the end of the period.

5-75
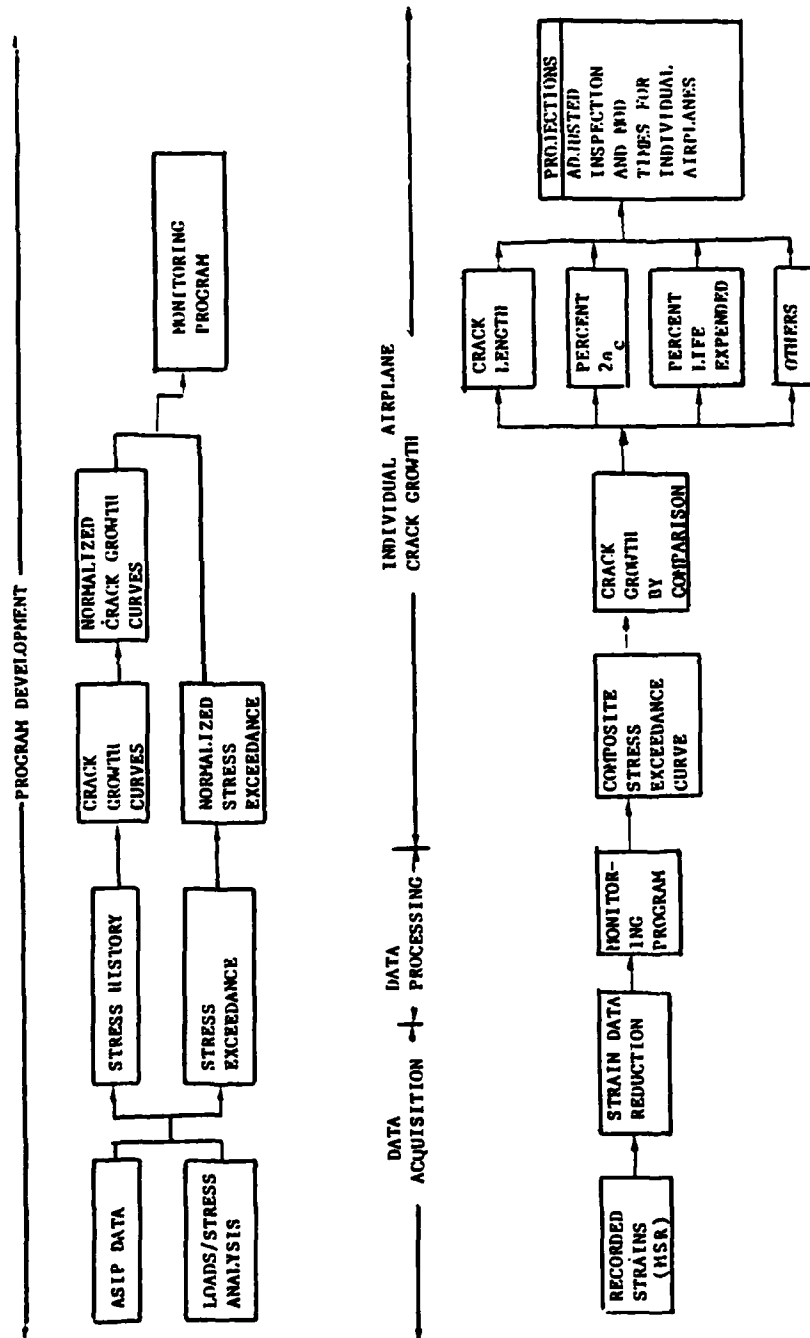
a) Tracking Procedure

Figure 5-23. Normalized Stress Exceedance Crack Growth.
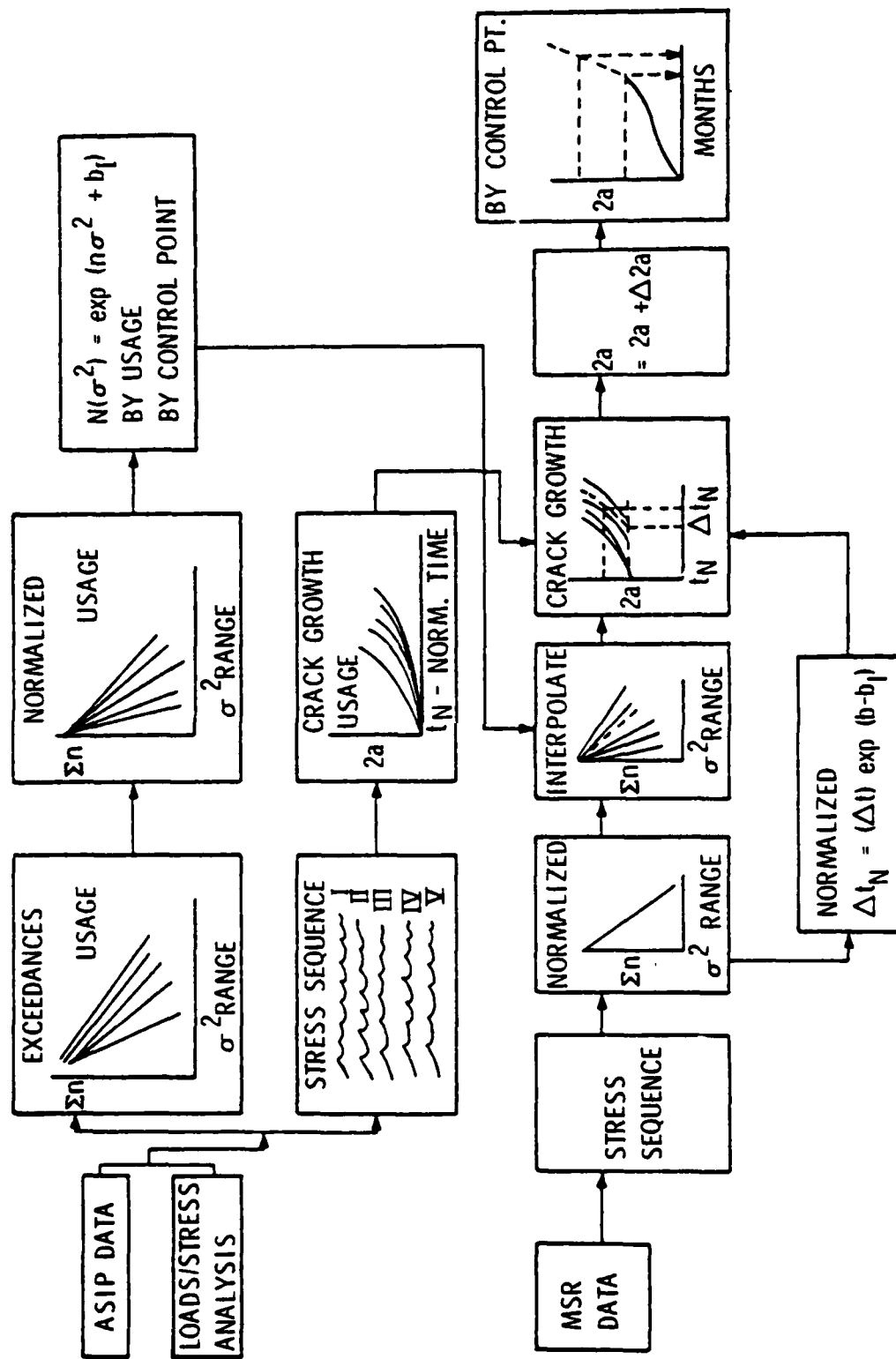
Figure 5-23. Normalized Stress Exceedance Crack Growth (Concluded).

b) Analysis Scheme
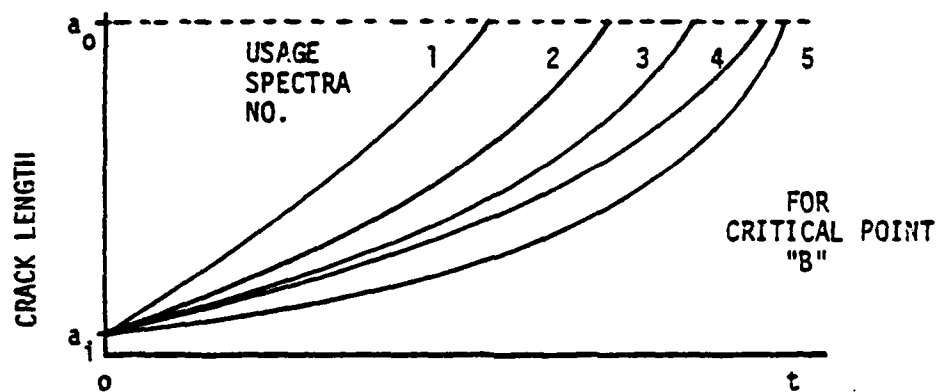
Figure 5-24. Crack Growth Curves for Usage Spectra.
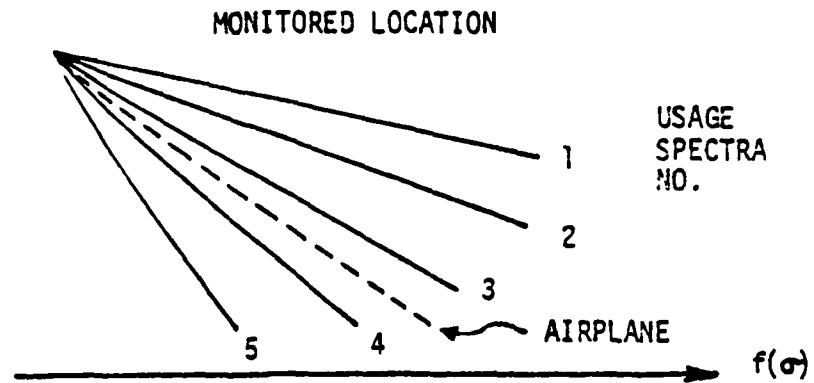
Figure 5-25.   Normalized Usage Spectrum.
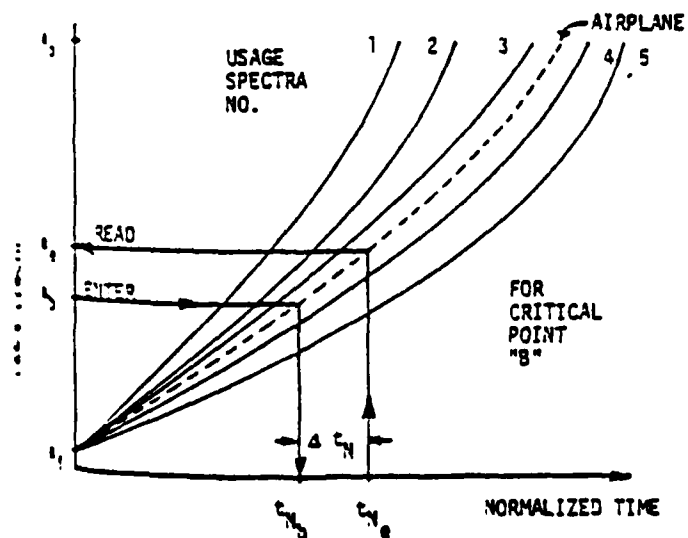
Figure 5-26.   Interpolation of Normalized Crack
Growth Curve.

5-79

Then finally the crack length (a_e) is read corresponding to the time t_{Ne} of the time period end. This is the current crack length at critical point B. The same is done for each critical location for each period.

5.2.4.4 Data Collection

The mechanical strain recorders are attached to the aircraft structure by two epoxy-bonded mounting blocks. Straining of the structure is transmitted to the drive mechanism of the recorder and scribed on the metal cassette tape by a diamond stylus. No external power source is required, and service experience on the existing models has indicated that maintenance is minimal.

The metal tape used as a recording medium is contained in a small cassette. To remove a recorded cassette and reload with a blank cassette requires very little time. The period of time to fully utilize the available tape depends on the sensitivity of the particular MSR and the activity of the airplane. In addition to the cassettes, IAT programs will require supplemental data describing aircraft operations over the period of time covered by the cassette. These data are submitted on forms.

5.2.4.5 Data Processing

The conversion of the analog stress peaks and valleys to a computer compatible digital format is accomplished by an automatic Data Transcriber Unit (DTU). The DTU is located at ASIMIS (Tinker AFB) and, hence, it is logical that the MSR data reduction be performed by this organization. A semi-automatic data reader at ASD (Wright-Patterson AFB) has also been used to transcribe data from MSR cassettes for limited programs.

Since an MSR records only strain peaks resulting from applied strain inputs, the possibilities for editing criteria are somewhat limited. Beyond the obvious checks of data validity, extreme cycles and exceedance rates should be tested for plausibility. In the event of missing data, gap filling will be performed from the supplemental data sheets if there is only one MSR on the airplane or parametrically from the output of a second MSR if available.

5-80

5.2.4.6 Cost Elements

The anticipated cost elements for the application of the MSR in the IAT function are listed in Table 5-12. If the MSR is to be used as a supplemental tracking device in transport/bomber aircraft, a rework and requalification of the gage to provide a lower threshold will be required. Further, the DTU will require modification to efficiently transcribe the large number of small stress cycles.

5.2.4.7 Accuracy

A strain history at a critical point certainly has the potential of providing the most accurate tracking system. The strain history can be reduced to a sequence of stress peaks and valleys and the input would be sufficient for any crack growth model in the forseeable future. However, in the practical application of a strain based IAT system, the ideal will not be achieved even if a cycle-by-cycle approach is used.

There are four sources of error that will be present in an MSR based tracking system: stress transfer; crack length transfer; missing data; and inaccurate recording or reduction. Errors due to stress transfer result from the non-deterministic relations between stress peaks at different locations in the structure. Correlations between stress peaks, that are acceptably high for most engineering applications, can produce significant error in crack growth predictions (Reference 2). The errors that result from parametric crack length estimates or transfer have not as yet been quantified. However, since strain measurements contain flight condition effects, parametric crack growth estimates from strain measurements are subjectively judged to be more accurate than those based on more remote activity indicators (e.g. counting accelerometers).

TABLE 5-12

IAT COST ELEMENTS FOR MSR TRACKING

ELEMENTS	MSR	COMMENTS FOR MSR SYSTEM
INITIAL DESIGN AND DEVELOPMENT OF DATA ACQUISITION DEVICE AND SUPPORTING EQUIPMENT		REWORK EXISTING MSR AND DATA TRANSCRIBER UNIT FOR TRANSPORT/BOMBER AIRCRAFT
DESIGN OF HARDWARE SYSTEM FOR SPECIFIC AIRPLANE	X	INSTALLATION DETAILS ONLY
QUALIFICATION TESTING		FOR TRANSPORT/BOMBER AIRCRAFT
DESIGN OF SOFTWARE SYSTEM FOR SPECIFIC AIRPLANE	X	COMPUTER PROGRAM
T.O. FOR IMPLEMENTATION	X	
FAB. AND INSTALLATION OF DATA ACQUISITION DEVICE AND SUPPORTING EQUIPMENT (SENSORS)	X	
REPLACEMENT OF DATA ACQUISITION ELEMENTS: TRANSMITTAL TO ASIMIS	X	CASSETTES
SPECIAL READING OF DATA ACQUISITION DEVICE		
DATA TRANSCRIPTION TO MAGNETIC TAPE	X	DATA TRANSCRIBER UNIT
COMPUTER ANALYSES OF DATA	X	STRAIN TRACE ONLY
GAP-FILLING	X	COMPUTERIZED
SUPPLEMENTARY DATA ACQUISITION; TRANSMITTAL TO ASIMIS	X	
ADDITIONAL COMPUTER ANALYSES OF SUPPLEMENTARY DATA		
MANUAL CHECKING, ANALYSES, DEBUGGING OF COMPUTER OUTPUT	X	MINOR
REPORTS OUTPUT	X	
ON-BOARD SYSTEMS MAINTENANCE		REPLACE MSR IF MALFUNCTIONING
TEST EQUIPMENT FOR ON-BOARD SYSTEMS MAINTENANCE		

5-82

Errors from missing data result from the
use of a flight hour as the activity indicator and the crack growth
being estimated in terms of an average increment per time unit.
The magnitude of potential error source depends on the reliability
of MSR devices. It is estimated that the MSR's will have a capture
rate in excess of 90 percent of possible flight time. The errors
that could result from inaccurate recording or reduction are
judged to be negligible when compared to the other error sources,
except that threshold problems may make the entire system unusable
for Transport/Bomber applications.

5.2.5   Microprocessor Based System

The recent advances in the field of electronic micro-miniaturization are expected to lead to an application of the technology to the task of IAT. The capability of microprocessor type devices is extensive and there are many distinct approaches that could be adopted in devising a scheme for tracking. The qualitative evaluation which follows explores the potential uses and goals for a microprocessor based system for transport/bomber IAT programs. A basic assumption of the system is that the required data can be processed as needed by the microprocessor including permanent storage and retrieval of the data. (Whether the on-board processing capability of the microprocessor should be utilized to its maximum potential is an unresolved question. An alternate, using the microprocessor only for data acquisition and systems checking is discussed in paragraph 5.2.5.9.)

A microprocessor-based system is conceptually described in Figure 5-27. The system includes on-board and ground processing of the data obtained from on-board sensors and manual (ground) inputs. It is assumed that both strain data and flight parameters are obtained.

The discussion which follows is based on seven assumptions:

1. It is desired that the microprocessor be as independent of any manual input as is possible. This is to minimize errors and omissions.

2. The aircraft is equipped with a flight computer and it is permissible to tie in to it to obtain inputs for the microprocessor. This ensures good primary input data at minimum installation cost.

3. The microprocessor system can be programmed to perform on-board calculations of crack growth data at desired locations based on aircraft flight parameters (VGH, events, etc.) or based on mission logic determined from these data and on pre-defined crack growth data for the resulting mission definitions
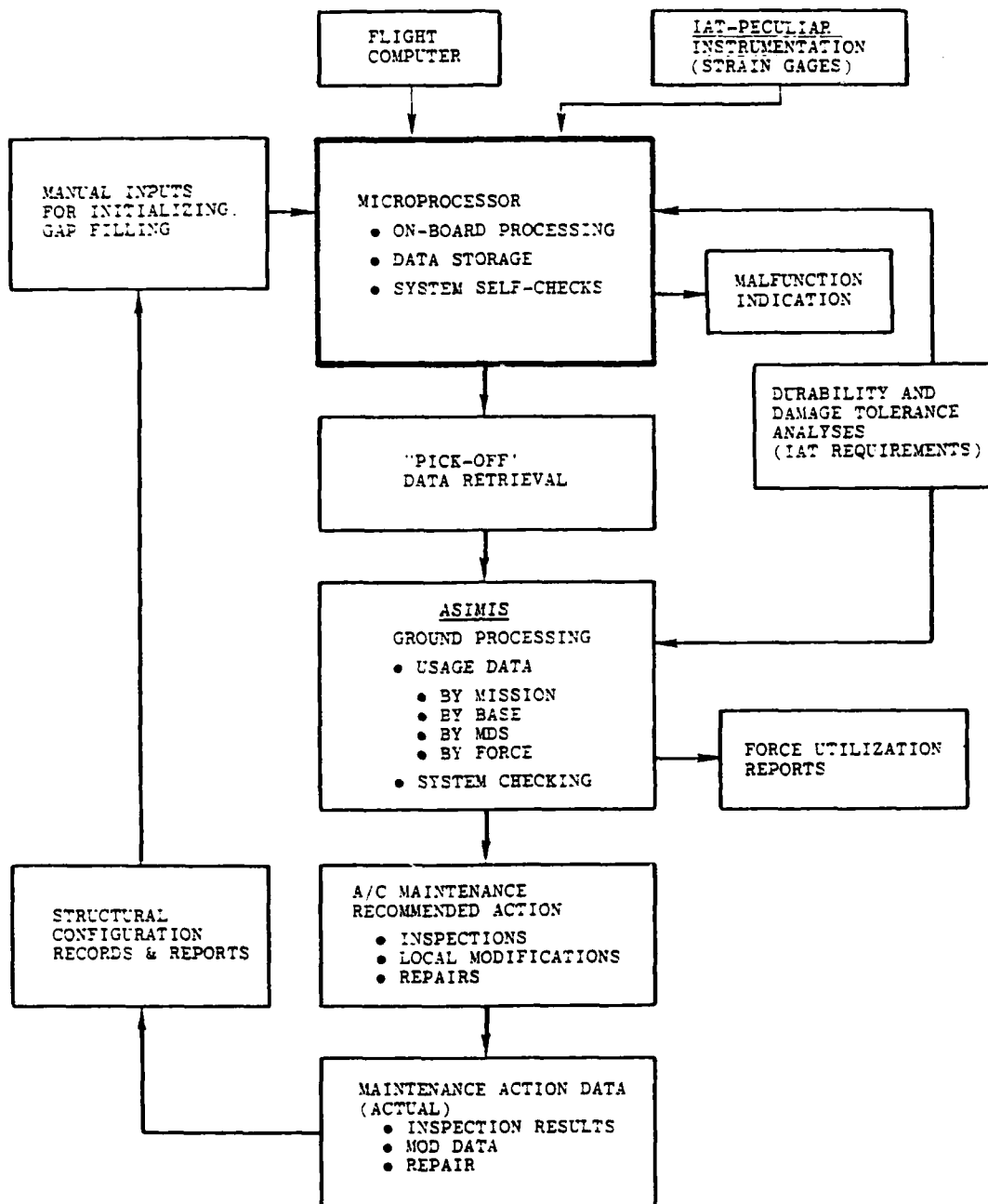
Figure 5-27. Microprocessor-Based IAT System Concept
On-Board Processing.

and variations. Alternatively, on-board crack growth calculations can be based on inputs and correlation from strain gages mounted at the desired locations or at nearby locations. It is assumed that the microprocessor is designed to output all three sets of data, for these reasons:

a) If a strain channel goes bad, the data will still be available from the VGH base;

b) Comparing the output of the strain-based and VGH based crack growth calculations will aid in evaluating both sets of data; and

c) Comparison of these data with the output from the mission logic system can provide significant information on the validity of the "average" mission logic based program to calculate the crack growth at individual locations with the specific individual aircraft experience. Since this system can be used for overall force data input for durability and damage tolerance analyses, the variation due to individual aircraft usage can benefit all further evaluations.

4) It is desired that the potential of the microprocessor be used to a significant extent in performing the individual aircraft tracking function, i.e., on-board processing of the data is desired to the extent practical.

5) Quality installations and high reliability of strain gages are assumed.

6) Some ground processing of data will still be required. As a minimum, the individual aircraft tracking program data would be reported by base, by mission, and by Force. The Force Management requirements of the Aircraft Structural Integrity Program (ASIP) Manager indicate that these data are needed. Inspection, maintenance, and operations planning are individual aircraft oriented, but within the context of overall Force requirements.

7) Modification of the microprocessor programs and retrieval of stored data can be accomplished by removing and inserting plug-in modules, referred to as "cards" herein.

The hypothetical on-board microprocessor system described herein obtains input, processes the data, and outputs the following:

a) Cycle-by-Cycle crack growth based on correlated strain gage readings.

b) Cycle-by-Cycle crack growth based on other aircraft flight parameters (VGH, event channels, etc.)

c) Crack growth based on interpretation of flight parameters into pre-defined mission descriptions and variations, and pre-programmed crack growth for these missions and variations.

d) Strain and other parameters occurrence data.

e) Mission descriptions and variations.

f) Recurring inspection data for monitor zones based on crack growth, NDI, and forecasting.

5.2.5.1   Advantages and Limitations

Potential advantages of the microprocessor based system are as follows:

a)   uses actual measured data,

b)   has potential to record sufficient data to realistically describe the airframe structural response history,

c)   can process data on-board,

d)   can combine IAT and L/ESS functions if so designed,

e)   can obtain inputs from other on-board equipment such as a flight computer,

f)   can be set up to receive flight crew inputs as keyboard entries,

g)   can perform automatic monitoring of non-standard flights and unanticipated events,

h)   can accomplish on-board data compression and storage,

i)   can accomplish system self-checks and indicate malfunctions for maintenance action,

j) potential to produce a high rate of data return,

k) compact data storage can be retained for later ground review or updating,

l) stored program updates can be readily accomplished through 'Card' Insert Approach,

m) compatible with other elements of Force Structural Management (L/ESS, FSM),

n) can provide data from actual strain experience and also from "calculated" usage.

Potential limitations and qualifications concerning microprocessor-based systems include:

a) must have proven high reliability through a combination of demonstrated actual on-board performance plus consistent periodic inspection and system maintenance

b) accuracy and calibration methods of input signals determine accuracy of the system

c) proper operation depends on installation quality, and longevity of input transducers (strain gages, accelerometers, altitude sensors, event switches, wiring, etc.)

d) must have initializing and special events data by maintenance personnel or crew if not obtainable from flight computer

e) system design requires definition before aircraft system characteristics are finalized

f) may depend on proper functioning of other equipment such as flight computer

g) system must provide flexibility for future program changes*

h) system must include output methodology and processing for ground-based analyses and summarizing/consolidation of data*

i) reliable power-down memory is required until data are retrieved.

---

* These requirements apply to other IAT systems also. However, since data processing for the other systems are ground-based, the microprocessor system must provide this capability as part of the design of the unit.

j) initial system acquisition costs greater than usage forms IAT

k) requires thorougᴴ systems checking methodology/procedure to assure operational readiness of on-board sensors

l) qualification program for on-board system must be performed

m) methodology/software changes will be difficult to effect, especially for large numbers of aircraft in series

n) malfunctioning microprocessor computer logic may be very difficult to detect

o) requires an almost uncompromising commitment on data reduction methodology early in the system development

p) on-board accounting for missing data (gap filling) will be difficult.

The advantages and limitations of the microprocessor-based IAT system result from its basic design characteristic: the microprocessor itself is an electronic mini-computer. Inputs must be keyed in or input electrically. In-place visibility is obtained visually by key querying or by malfunction signal lights. All other visibility must be obtained by reading memory cards using ground equipment, or otherwise evaluating the electrical signals stored in the microprocessor. And finally, the microprocessor monitors only the individual aircraft in which it is installed - it has no ability to combine Force data by base, by mission, by Force, etc.

It must be cautioned that the microprocessor not be considered a panacea for all IAT problems; it still shares most of the basic overall system characteristics of the usage forms IAT, and has additional considerations such as electronics complexity and initial cost of development, hardware, and installations. However, the present usage forms IAT system cannot reflect direct

actual flight environment and response; in this respect, the micro-processor system can provide valuable data. Both systems require much forethought and software planning; crew inputs of some amount; some amount of ground processing and data; structural inspection data feedback and input; and manual ("people") review, assessment, and implementation of results from the data. Self-checks and trouble lights must be designed into the microprocessor since the calculations cannot be monitored. Flexibility for updates to the system must be provided. The advantages of the microprocessor lie in the area of on-board sensors and capability for electronic data gathering and processing. The quality of program output could potentially improve operational aircraft safety through more individually responsive inspection calculation data. Whatever system is utilized in the future IAT programs will always require experienced structural engineers to monitor and interpret the data. The use of electronic means for data gathering can provide useful information for decisions on safely managing an airframe system.

5.2.5.2 Stress Transfer Functions

Transfer functions to base analyses at one location on data acquired at another location will depend on the parameters and type of analyses involved.

a) The microprocessor system can be programmed to calculate crack growth data at desired locations based on aircraft flight parameters (VGH, events etc.). These inputs would be translated into loads/stress exceedance and crack growth using structural Load/Stress/Deflection characteristics based on data from the aircraft design and structural analysis, flight test, and L/ESS programs. Each monitor location could have its own program logic, and usage of transfer functions between locations are not envisioned to any large extent.

b) The aircraft parameters of (a) above can be translated by mission logic into "standardized" missions and variations thereof, and crack growth calculated using pre-defined data for these missions and variations. These calculations, made after the flight by the microprocessor (or, alternatively, by

later ground processing) would use stored crack growth data for each location, and no transfer functions would be used.

c) Crack growth can be calculated "on-board" using correlated strain gage signals as the only input. Transfer functions to relate the strain at one location to that at another nearby location might be possible in a limited sense using the predicted strain relationship between the desired location and the gage location; detail stress and crack growth analysis for the various airframes would be required in assessing this possibility. Dynamic response, natural frequencies, and six-component loading effects may seriously limit the applicability of such transfer functions; however, the crack growth calculations may still be more realistic than the calculations of method (b) using statistical environmental loads and response data.

5.2.5.3   Crack Growth Models/Examples

Figure 5-28 is a conceptual flow diagram for a microprocessor based crack growth IAT. On-board processing and mission-definitions crack-growth calculations are shown.

5.2.5.4   Data Collection

Microprocessor-based IAT systems can be designed to be relatively independent of crew input. Prior to each flight, initializing data not obtainable from aircraft sensors such as cargo weight and stores weight (if these are not obtainable from a flight computer) could be input. Certain data are efficient and practical as performed by hand input; however, an overall goal is to obtain as much required data (including time) automatically as is practical. The purpose of this method is to minimize errors and omissions. The complexity of the individual system and data that are available from the flight computer will affect the decisions on how to address specific parameters or events. The microprocessor can be designed to obtain and process certain data on-board and also to store other data for later ground processing analysis. Changes to the program such as configuration status changes and inspection results (resetting calculated crack lengths to detectable
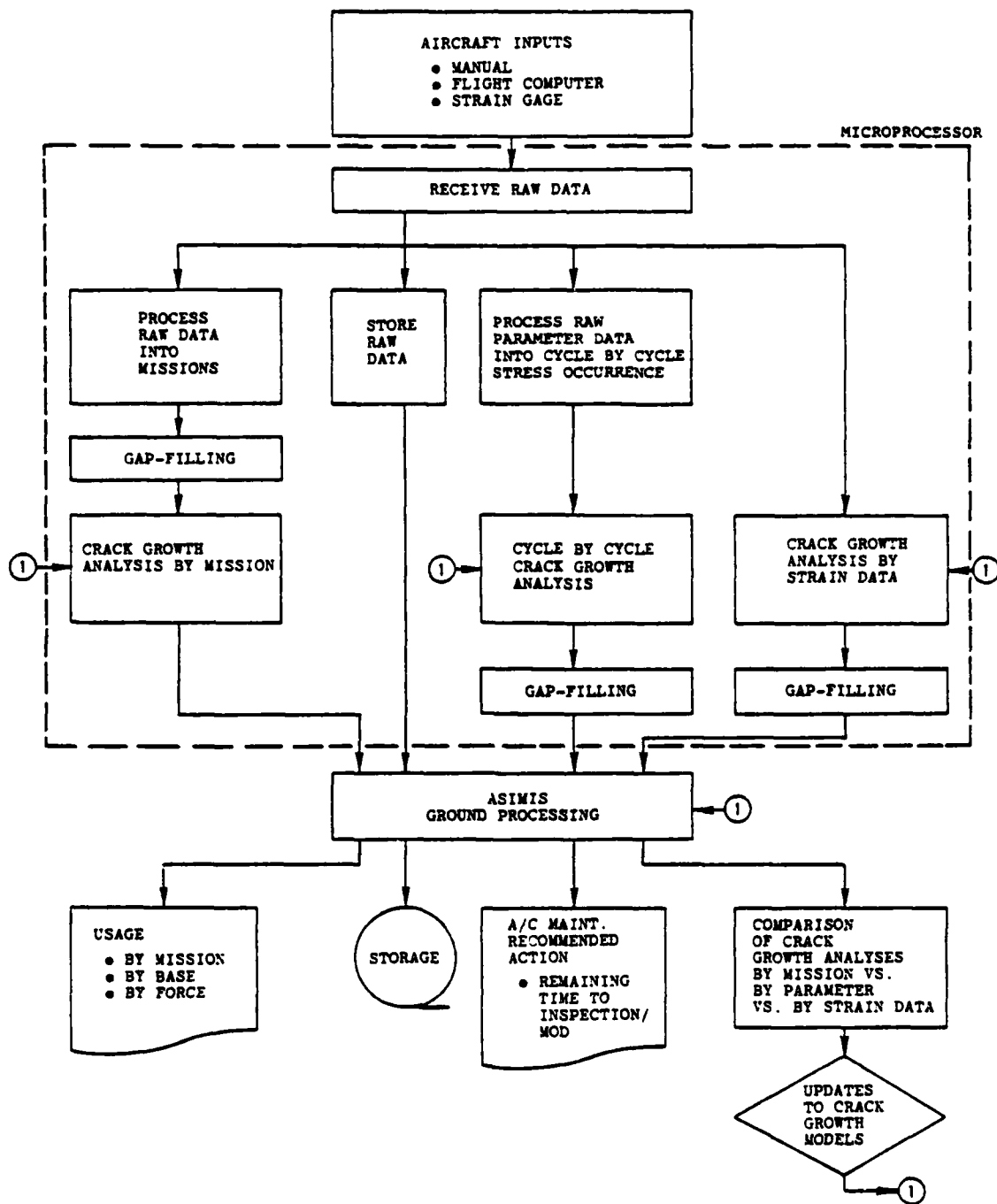
Figure 5-28. Microprocessor Crack Growth Model -
Conceptual Flow Diagram.

length) could be accomplished by the maintenance crew, using pre-
printed cards provided by ASIMIS or the ALC.

At the appropriate interval, some system,
such as a "pick-off" hookup that sends the data to ASIMIS by
telephone line and erases the memory card, could be employed to
transmit the pre-processed data to a ground facility for calcula-
tions of Force usage by mission, by base, etc. Computerized output
of the same basic data as is obtained from the usage forms IAT
with output variations to show such items as calculated crack growth
based on recorded strains or on other parameters and pre-defined
mission crack growth, could be programmed.

5.2.5.5 Data Processing

Verification and editing capability can
be designed into the microprocessor and accomplished on-board.
This checking should consist of reasonability checks and operational
boundaries similar to those presently included in the ASIMIS IAT
and L/ESS computer programs. In addition, verification and editing
checks presently utilized in the ASIMIS IAT computer programs
should be employed to check the microprocessor output. The memory
of the microprocessor should include data check information on
non-automatic (manual) inputs such as the basic crack length for
the calculations, in order that later ground processing can check
these data.

Gaps in microprocessor IAT data may be
caused by various factors such as: malfunctioning equipment; air-
craft usage exceeding the memory capacity of the microprocessor;
or by data cards not being read/replaced or programs updated at
the proper time. (Program updating could consist of resetting the
initializing crack length when an inspection has been performed.)
Gap-filling procedures will therefore fall into two classifications:
procedures for on-board calculations and procedures for ground
processing/verification/compilation operations.

5-94

For the on-board microprocessor, several approaches to gap-filling may be considered:

1. Gap-filling can be omitted. This results in "pure" data for later ground processing, but the on-board processing may be unconservative, i.e., the output may not reflect the total usage of the airplane.

2. Gap-filling can be based on force average mission profiles or on the most severe usage predictions, applied to the gap in flight hours which is to be filled. This will require that pre-defined data or a damage projection equation be included in the microprocessor.

3. Gap-filling can be based on the actual usage recorded by the microprocessor in the immediate past history. The crack growth gap-filling projection can be a linear extrapolation of the crack growth increment over the immediate past history; a curve-fit extrapolation; or some other method appropriate to the crack growth calculations methodology. The usage (mission descriptions) data stored in the microprocessor can also be incremented based on the recently acquired usage data for that airplane.

In any of the above cases, storage of information to identify the gap-filled segments is needed. Also, the microprocessor logic for gap-filling must be carefully designed. The microprocessor must recognize that some data are erroneous, reject these data, and then gap-fill based on the flight hours missed. Assuming that strain data are being processed on-board and that a significant gap could extend from time of occurrence until the malfunction is corrected by ground maintenance, it would appear that the gap-filling should be accomplished at the time the maintenance is performed. Logic based on flight hours at the beginning of the gap and at the end (input by card or keying in flight hours after the maintenance) could trigger the microprocessor to gap-fill.

The ground processing activity should also have gap filling considerations. The percent of flight hours of required gap filling could be output for individual aircraft; by base; by mission; and by overall fleet or force as an indication of the "impurity" of the data. For verification and studies of the data, however, the ground processing system could operate on the "pure" stored usage data from the microprocessor.

5.2.5.6 Cost Elements

Table 5-13 lists cost elements which may be anticipated for a microprocessor based system. It is assumed that the microprocessor system is to be used on an aircraft which already has a flight computer, i.e., all inputs can be obtained from existing instrumentation except the strain gage channels.

Initial costs will be higher than for the (baseline) usage forms IAT system because of the cost of the microprocessor and the installation. Later ground processing costs can be reduced if data are kept but not analyzed. Data yield and realism may be imporved over the baseline usage forms IAT program if the reliability of the total system is achieved. Also, if the microprocessor is used in a combined IAT and L/ESS system, the cost projection becomes more favorable. (See Section 6.2.3).

5.2.5.7 Accuracy

The requirements of microprocessor based IAT may vary for different aircraft from a minimum strain gage or V.G.H. based system to the system described herein but independent of a flight computer, i.e., requiring that all instrumentation inputs be installed specifically for the IAT system. Also, the IAT system can be independent from the L/ESS system or the two can be combined. The best approach for each aircraft must be determined on its own needs.

For existing aircraft, the decision of substituting a microprocessor-based system for the present usage forms (and MXU 553A L/ESS) system must also be determined for each aircraft. In general, it is considered that existing or near-term Fracture Tracking (IAT) Programs should be retained.

TABLE 5-13

IAT COST ELEMENTS FOR TRANSPORT/BOMBER
MICROPROCESSOR BASED IAT SYSTEM

ELEMENTS	MICROPROCESSOR	COMMENTS FOR MICROPROCESSOR SYSTEM
INITIAL DESIGN AND DEVELOPMENT OF DATA ACQUISITION DEVICE AND SUPPORTING EQUIPMENT	X	MICROPROCESSOR & DATA PICKOFF DEVICE
DESIGN OF HARDWARE SYSTEM FOR SPECIFIC AIRPLANE	X	MICROPROCESSOR CIRCUITS,SENSOR INST'L, TIE-IN TO FLIGHT COMPUTER
QUALIFICATION TESTING	X	
DESIGN OF SOFTWARE SYSTEM FOR SPECIFIC AIRPLANE	X	GROUND PROCESSING AND ON-BOARD CHANGEABLE COMPUTER PROGRAMS
T.O. FOR IMPLEMENTATION	X	
FAB. AND INSTALLATION OF DATA ACQUISITION DEVICE AND SUPPORTING EQUIPMENT (SENSORS)	X	
REPLACEMENT OF DATA ACQUISITION ELEMENTS: TRANSMITTAL TO ASIMIS	X	PICKOFF OF DATA
SPECIAL READING OF DATA ACQUISITION DEVICE		
DATA TRANSCRIPTION TO MAGNETIC TAPE	X	PICKOFF DIRECTLY TO MAG. TAPE
COMPUTER ANALYSES OF DATA	X	SOME ANALYSES MAY BE ON-BOARD
GAP-FILLING	X	ON-BOARD (MANUAL INPUT-COMPUTERIZED) OR ON-GROUND (COMPUTERIZED)
SUPPLEMENTARY DATA ACQUISITION; TRANSMITTAL TO ASIMIS		
ADDITIONAL COMPUTER ANALYSES OF SUPPLEMENTARY DATA		
MANUAL CHECKING, ANALYSES, DEBUGGING OF COMPUTER OUTPUT	X	
REPORTS OUTPUT	X	
ON-BOARD SYSTEMS MAINTENANCE	X	
TEST EQUIPMENT FOR ON-BOARD SYSTEMS MAINTENANCE	X	

Should a microprocessor system become available in the near future, it could be used in conjunction with existing IAT's as a developmental phase; candidates could include C-141B, C-5A, B-52, and the KC-10.

Force Management planning should assume that both usage forms IAT and microprocessor IAT systems will be run concurrently for sufficient time to establish the reliability and characteristics of the new system. This will increase initial costs due to duplication of effort and comparative analyses.

The data obtainable from the microprocessor IAT system respond to in-flight strain or load conditions and are therefore more realistic than the "average" data used for the usage forms IAT. On-board, cycle-by-cycle processing will accomplish directly what the usage forms IAT approximates in pre-defined data. However, it should be recognized that additional costs will be attendant to evaluating these data in the initial stages of the microprocessor IAT program. As later generation microprocessors become available, more of the ground processing burden can be reduced as on-board processing is accomplished with a minimum of ground checking.

5.2.5.8 Realism

Three analysis methods are recommended to be used by the microprocessor (See Section 5.2.5.3): strain gage based calculations; IAT parameter-based calculations; and mission classification/crack growth by mission calculations. The realism of each method depends on the accuracy and calibration of the input data (strain gages, accelerometers, etc.) and the characteristics of the analysis programs. However, the actual individual aircraft experience is reflected by the strains, accelerations, and other parameters which are translated by the microprocessor into IAT data (occurrences, crack growth calculations and projections, and mission definitions). Therefore, the realism will be improved relative to predefined data from the usage forms IAT programs. Also, the data yield of the microprocessor system can be better than that of the usage forms system, assuming that high sensor reliability is

achieved. The possibly improved data yield (due to less manual input of data) for most aircraft may also increase the realism because less gap-filling may be necessary. As compared with a system based on "g" counters, the microprocessor not only allows "g" consideration but also uses the aircraft configuration and loading source for each "g" encounter, thus improving the realism of the crack growth analyses for the structural monitor locations.

The realism of crack growth calculations from strain gage data depends on the accuracy and calibration methods for the strain gage channels. Calibration can be set initially and checked at specific intervals (such as yearly) by on-loading known fuel weights. Between calibrations, the microprocessor can automatically check the calibration at each fueling. Zero shift corrections can be made automatically at an appropriate time in each flight, based on known flight parameters and a 1g flight condition. Despite these procedures, however, it should be recognized that the reliability of strain gage data tends to be somewhat questionable.

5.2.5.9   Alternate Approach: Microprocessor for
           IAT Data Acquisition and On-Board System
           Checking

The system described above maximizes on board processing of the IAT data. A viable alternate is to automate the data acquisition by the microprocessor but to continue ground processing of the data. The microprocessor can also be used for on-board systems checking and malfunction indication, to improve the quality of data and minimize "gap-filling" by alerting the maintenance crew to systems problems needing correction. This system is described in the paragraphs which follow.

Figure 5-29 is a concept diagram of an IAT system using a microprocessor for data acquisition and on-board systems checking. Desirable design goals for such a system could be:

a) An optimum mix of manual (keyed-in) and automatic data inputs;
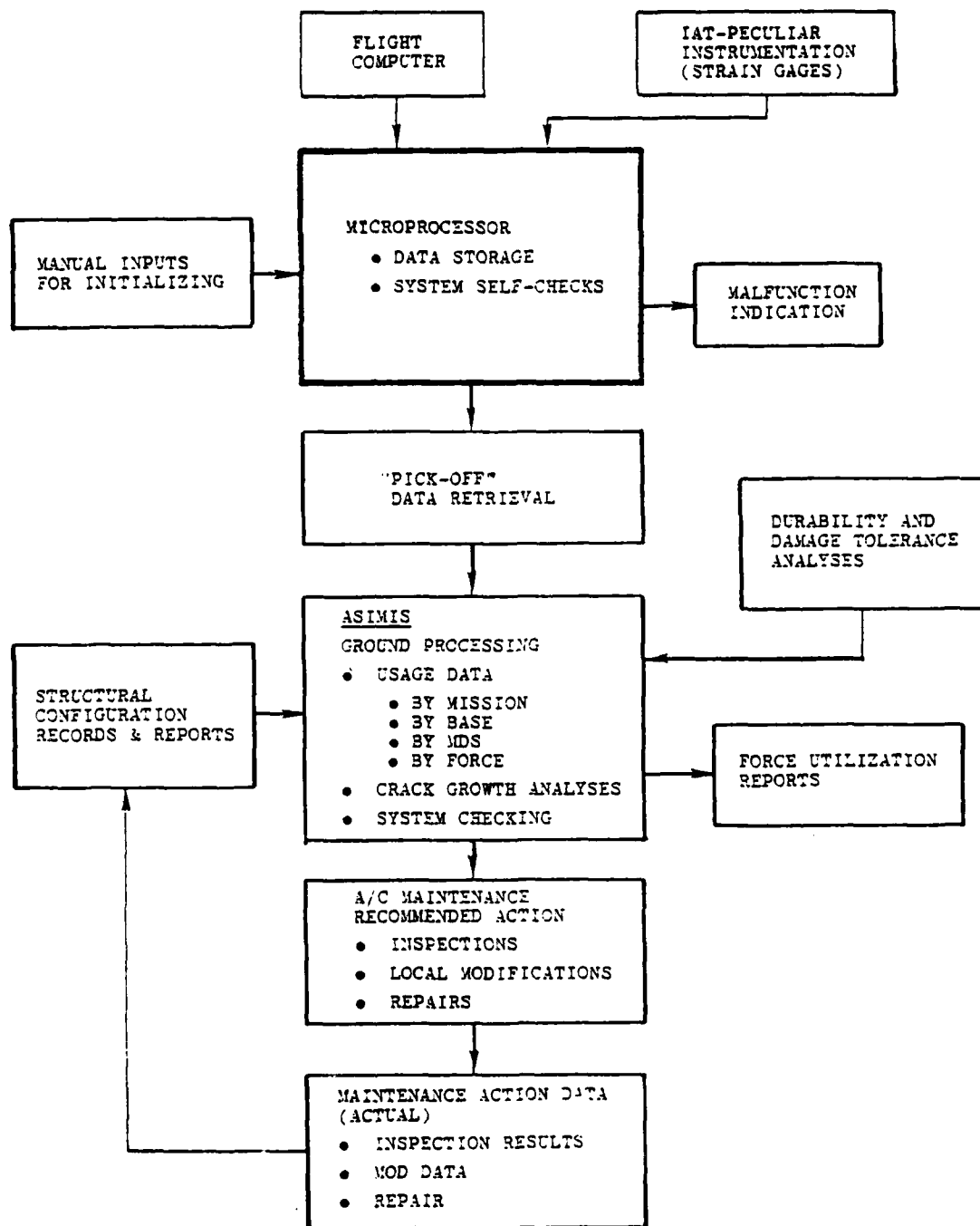
Figure 5-29. Microprocessor Concept for IAT Data
Acquisition and On-Board Systems Checking.

b) Tie in to the flight computer, for good primary input data at a minimum installation cost,

c) On-board checking of the sensor systems and visual indicators for malfunctions,

d) Acquisition and "pick-off" output of sequenced strain peaks and sequenced parameter/event data against a time base,

e) All data processing and evaluation is accomplished at ground facilities.

The primary features of this system are the same as those for the "on-board processing" system. However, this system has the advantage that computer logic, updates, program changes, gap-filling, evaluations, etc., are all accomplished at a central (ASIMIS) ground facility. It is not necessary to update or change the many microprocessors in the many service aircraft throughout the country when these changes are necessary. Also, it is logical to assume that the advances in electronics technology which permit the development of these microprocessors with greatly increased storage capacity will also produce ground processing computers which can handle the processing for all the data acquired by these microprocessors.

The primary disadvantage of this system is the cost of performing all processing at the ground facility.

Inputs for the microprocessor in this system are the same as for on-board processing except that initializing data for crack growth calculations and gap-filling are not necessary. The microprocessor functions and the required crew inputs are both simplified significantly by this approach. Other advantages and limitations as for the "on-board processing" system, listed in paragraph 5.2.5.1, also apply with the obvious modifications resulting from a data acquisition rather than an "on-board processing" concept.

Inputs and outputs of the ground processing for the microprocessor system are the same as for the present usage forms IAT program, except that the microprocessor output (input to the ground processing system) will be much more extensive and detailed than that from the present usage forms. More extensive data logic and more extensive storage will be necessary to handle these data. The IAT microprocessor output (input to ground processing system) will be somewhat like that from the present MXU-553A L/ESS output, including strain peak counts and parameter combinations.

In general, other Paragraphs of the "on-board processing" system apply for the data acquisition microprocessor system also. The difference between the systems relate to flexibility and cost. It would appear that the best use of a microprocessor for Transport/Bomber IAT programs would be to use the microprocessor for data acquisition and on-board systems checking, in order to retain the flexibility of the ground processing. "On-board processing" may be desirable after the IAT program is thoroughly worked out; however, future cost analyses are needed to compare/evaluate the cost savings of on-board processing (with respect to ground processing) against the added initial expense and complexity of the "on-board processing" microprocessor and the inputting to it of initializing and gap-filling data.

Additional study is recommended to determine whether the "on-board processing" system or the data acquisition/ systems checking microprocessor is more appropriate for a particular aircraft IAT. It should be noted that continuing advancements in microprocessor and computer state of the art are so rapid that any evaluation at the present time is premature. However, these rapid changes in state of the art also lead to the conclusion that the data acquisition/systems checking microprocessor approach is more appropriate as a near-term method. Parallel operation of this system and the usage forms IAT system would provide experience with the microprocessor system while retaining the known characteristics and reliability of the usage forms program.

The installation and maintenance costs and the lack of confidence in the strain gage channels are major reservations in the use of a microprocessor based IAT system. A very practical solution to this problem is to delete the strain channels and use only the available flight computer data and the necessary supplementary data. Strain data could be obtained and utilized as part of the L/ESS Program (only). This solution appears to have merit beyond the more idealistic IAT System presented in this Section 5.2.5.

It must be noted that to the extent that they are installed solely for the IAT, the use of a microprocessor system entails the additional complexity of maintaining sensors and electronic equipment. Experience with the present MXU-553A L/ESS system indicates that for these non-flight-critical installations, adequate sensor maintenance is difficult to obtain in the "real life" situation. The microprocessor can be designed to signal a need for maintenance, but the maintenance itself will be an added burden over the present usage forms IAT system and is not much more likely to be performed in a timely and effective manner for the IAT system than it has been to date for the existing L/ESS systems. Paralleling the flight-critical flight computer systems where possible will minimize this problem.

Certain data inevitably must be keyed in or obtained from a supplementary data sheet regardless of the sophistication of the microprocessor system. If these supplementary data are to be logged on a data sheet, the conclusion naturally follows that the present usage forms are an excellent means of gathering the supplementary data. It would not be necessary to process the data paralleling the microprocessor output unless the microprocessor output were missing or a comparative evaluation were desired.

5.2.6 Crack Growth Gage

The crack growth gage (CGG) method involves the attachment of a small precracked coupon to aircraft primary structure at a designated location. Crack growth from assumed initial flaws in the aircraft can then be related to the CGG crack growth, Figure 5-30. The use of a crack growth gage (CGG) as a usage severity indicator can provide a direct response to actual cyclic strain experience of the airframe at a specific structural location. If the crack growth experience of the gage can be correlated to the crack growth characteristics of the actual structure to which it is attached, then a potential exists to obtain very useful data to supplement a total Fracture Tracking Program. One of the principal advantages of such a system would be in providing a relatively low cost means of 'Fine Tuning' the periodic inspection requirements of a given tail number at a serieS of structural monitor locations. This assumes that a reliable CGG system can be perfected and 'flight hardened' and that analytic correlation can be developed at each of the necessary structural monitor locations. It is further assumed at this stage that the CGG is intended to respond to the safety-based periodic inspection range of crack growth. For example, this corresponds to crack size intervals from 0.15" to 1.5" on the C-141A wing structure.

Development of the CGG to date has shown some problems of repeatability and spectrum sensitivity. The qualitative analytical evaluation presented in the following paragraphs is predicated on the assumption that these problems can be resolved through additional CGG hardware development, i.e., the gage will give predictable results (within "acceptable" limits). This assumption is necessary to a viable crack growth gage system. Two other assumptions are made: (a) the CGG response to various spectra displays spectrum sensitivity effects, but these effects are "reasonably small," and (b) the crack growth in the gage is different from the growth in the monitored airplane structure, but the relationship between them can be "reasonably" established.
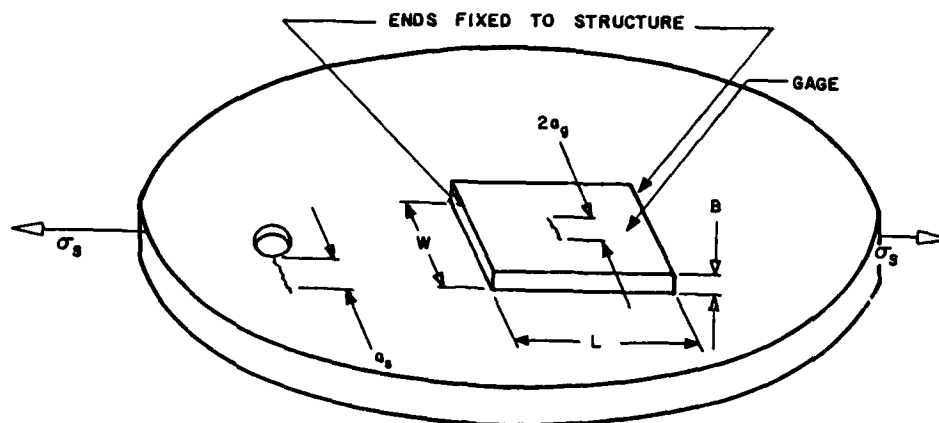
a) Schematic View of Crack Growth Gage Attached to Flawed Structural Component.
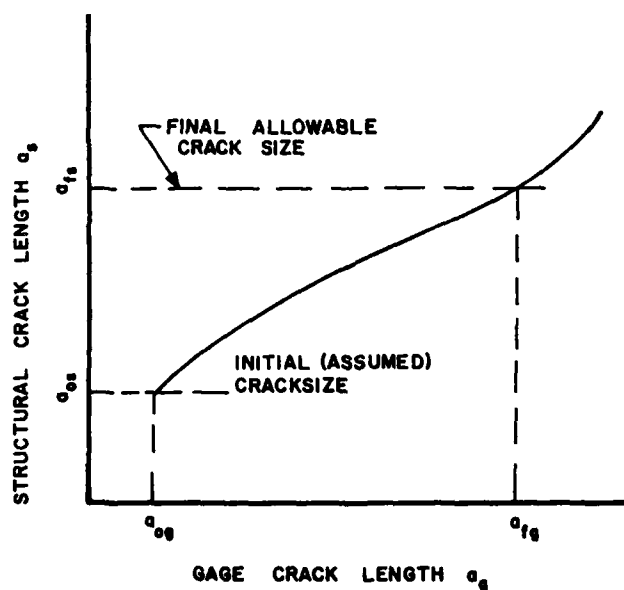
b) Schematic Representation of the Relationship Between the Gage and Structural Flaw Sizes.

Figure 5-30.   Correlation of Crack Growth Between Crack Growth Gage and Structure.

The following paragraphs present one approach to the use of a CGG in an IAT program. The example is presented in terms of a transport/bomber aircraft but similar concepts would apply to attack/fighter/trainer aircraft.

Figure 5-31 illustrates the crack growth gage concept on which the example application is based. The CGG of a structural element is removed at the end of a Programmed Depot Maintenance (PDM) interval and initial and final lengths are measured (upper left sketch). The measured lengths are input to curves of CGG response from laboratory tests of benign, average, and severe usage to determine the degree of usage severity indicated by the gage, closely matching spectrum hours used by gage to flight hours between PDM interval type usage (lower left sketch). This severity of usage is used with the analytical crack growth characteristics at a given structural location and the previously determined analytical length of the crack at the location at the beginning of the PDM interval (i.e. a_i^{**}) to determine the current potential crack length (a_f) in the structure (lower right sketch). Finally, the potential crack lengths in the structure over successive PDM intervals define the crack growth history and projections for that aircraft at that location (upper right sketch). Maintenance actions recommendations are based on this information. When an inspection is performed, the analytical crack length is reset to the NDE detectable length (a_{NDE}^{**}).

Of several ways in which the crack growth gage system can be structured. this hypothetical system has the following characteristics:

(a) The crack growth gage is sized to produce measurable crack growth during a normal base level inspection interval, but not to fail (crack apart) in this interval.

(b) The initial and final length for the flight hours flown during the measured interval are used as indicators of the severity of usage of the individual airplane at the specific monitored location(s).

5-106

FIGURE 6.2.2.6.1 - CRACK GROWTH GAGE
CONCEPT FOR INDIVIDUAL AIRCRAFT TRACKING

Figure 5-31.   Crack Growth Gage Concept for Individual Aircraft Tracking.
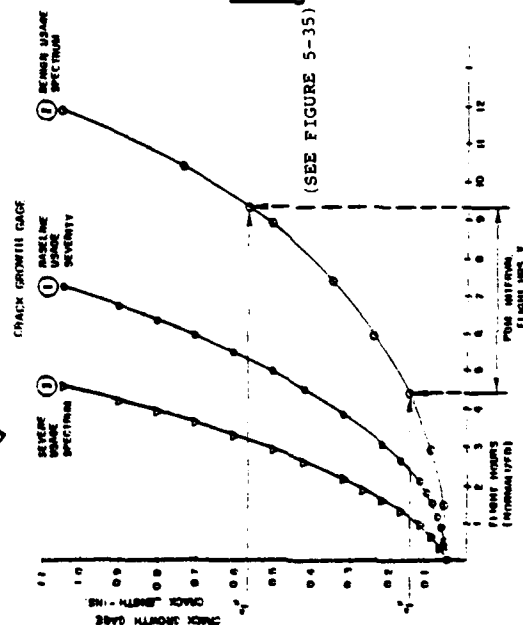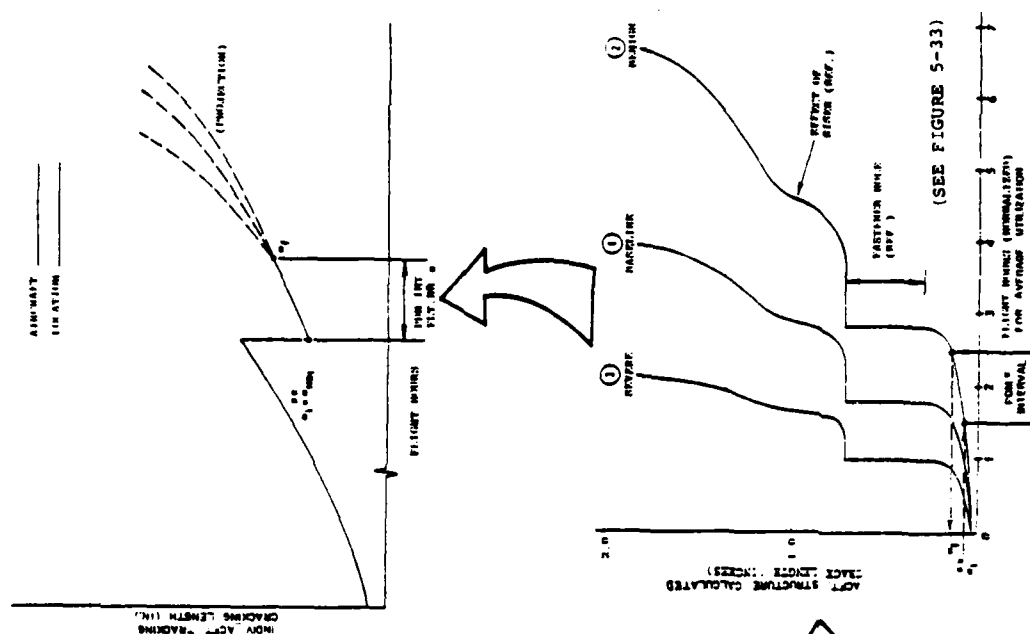
(c) The safety-based analytical crack length in the individual airplane structure is incremented based on the usage severity indicated by the crack growth gage. This may be accomplished by automated computer routines, which reflect the proper correlation between the CGG and the actual airframe hardware.

Experience with crack growth test coupons under laboratory conditions indicates that large scatter is obtained in externally reading both the initial crack length and the present crack length. Other methods of obtaining crack length data without removing the crac.. growth gage are available, such as laboratory examination of crack face impressions made using Faxfilm replicating tape. (See Reference 10). However, it is considered desirable for Transport/Bomber aircraft to remove and replace the crack growth gage at intervals in order to use a sufficiently responsive gage design. (See Paragraph 5.2.6.7). Therefore, it is considered that destructive inspection of the CGG crack surface should be planned to obtain crack growth measurements with sufficient precision to use the data for correlating with analytical crack length calculations at specific structural monitor locations on individual aircraft on which the CGG's are mounted.

One possible approach (which might be termed the "traditional" or "idealized" approach) to the design of a CGG system is to use the usage severity indication of the CGG as a direct monitor of the airplane's experience, and to take inspection/modificationa action when the CGG crack reaches a specified length or cracks across. The design of the CGG is tailored to the specific aircraft structural location where it is mounted, and its crack growth characteristics with respect to the aircraft structure are established by correlation analyses. The approach is not used as the baseline of this report section, however, because of practical problems for Transport/Bomber aircraft such as are discussed throughout this section. The problems relating to spectrum sensitivity (Paragraph 5.2.6.2), logistics difficulties in determining the length of the CGG crack (Paragraph 5.2.6.4), and confidence in performing service aircraft inspection/maintenance

action based on the CGG results (Paragraph 5.2.6.7) appear to be more severe for this "idealized" approach, in which one crack growth gage is bonded to the airplane one time, crack length is determined by on-the-airplane measurements or Faxfilm methods, and service inspection/maintenance action is based on CGG length without resort to any supplementary data, than for the method described herein.

5.2.6.1   Advantages and Limitations

Advantages of the Crack Growth Gage (CGG) are:

(a) Responds to temperature, creep, load environment as does the basic aircraft structure.

(b) Simple mechanical system – "no moving parts".

(c) Potentially can be designed to minimize field level maintenance.

(d) Compact, self-contained unit.

(e) No power source is necessary.

Limitations of CGG are:

(a) Repeatability and spectrum sensitivity problems are not yet resolved.

(b) Must be installed at a structurally significant, accessible location.

(c) Bond line variations (installation techniques) must be perfected.

(d) Reliable, accurate readout method must be established.

(e) Missing or unreliable data can affect a significant time span of usage.

(f) Requires supplementary data for Transport/Bomber Aircraft.

(g) Long-time interval between data readouts if accomplished at base level intervals.

(h) Readout may be out of phase with inspection actions by up to one base level (PDM) inspection interval.

(i) Methodology of precracking and establishment of initial crack size not yet finalized.

(j) Correlation methods to relate CGG crack growth to actual airframe crack growth not yet finalized.

5.2.6.2　Stress Relationships

For the crack growth gage system described herein, the gage operates as a "usage severity indicator" and a gage at one structural monitor location can potentially represent the usage severity at other locations having similar basic severity parameters.

Additional crack growth gage installations may be necessary for locations where other usage severity parameters apply. For example, an aft fuselage structural monitor location which is sensitive to pressurizations, empennage loads, and ground loads would not be expected to be well represented by a wing mounted crack growth gage. Additionally, outer wing structure affected by aileron inputs, load alleviation control systems, and aerial refueling operations would respond differently from wing root structure. Study of the individual aircraft is required to determine the extent to which a crack growth gage at one location can be considered representative for such other locations.

5.2.6.3　Crack Growth Models/Examples

Figure 5-32 is a conceptual flow diagram for a crack growth gage based IAT. Figure 5-31 shows hypothetical crack growth curves for a transport/bomber (based on C-141A) wing structure and for a hypothetical crack growth gage. The approach shown can be operated manually using parametric curves for several usage severities, or it can be computerized with curve fit or tabular data matching routines.

In this approach, the usage severity is classified into 'bands' for analysis. For the example shown, three levels or 'bands' of spectrum severity are selected and crack growth characteristics of the specific structural monitor
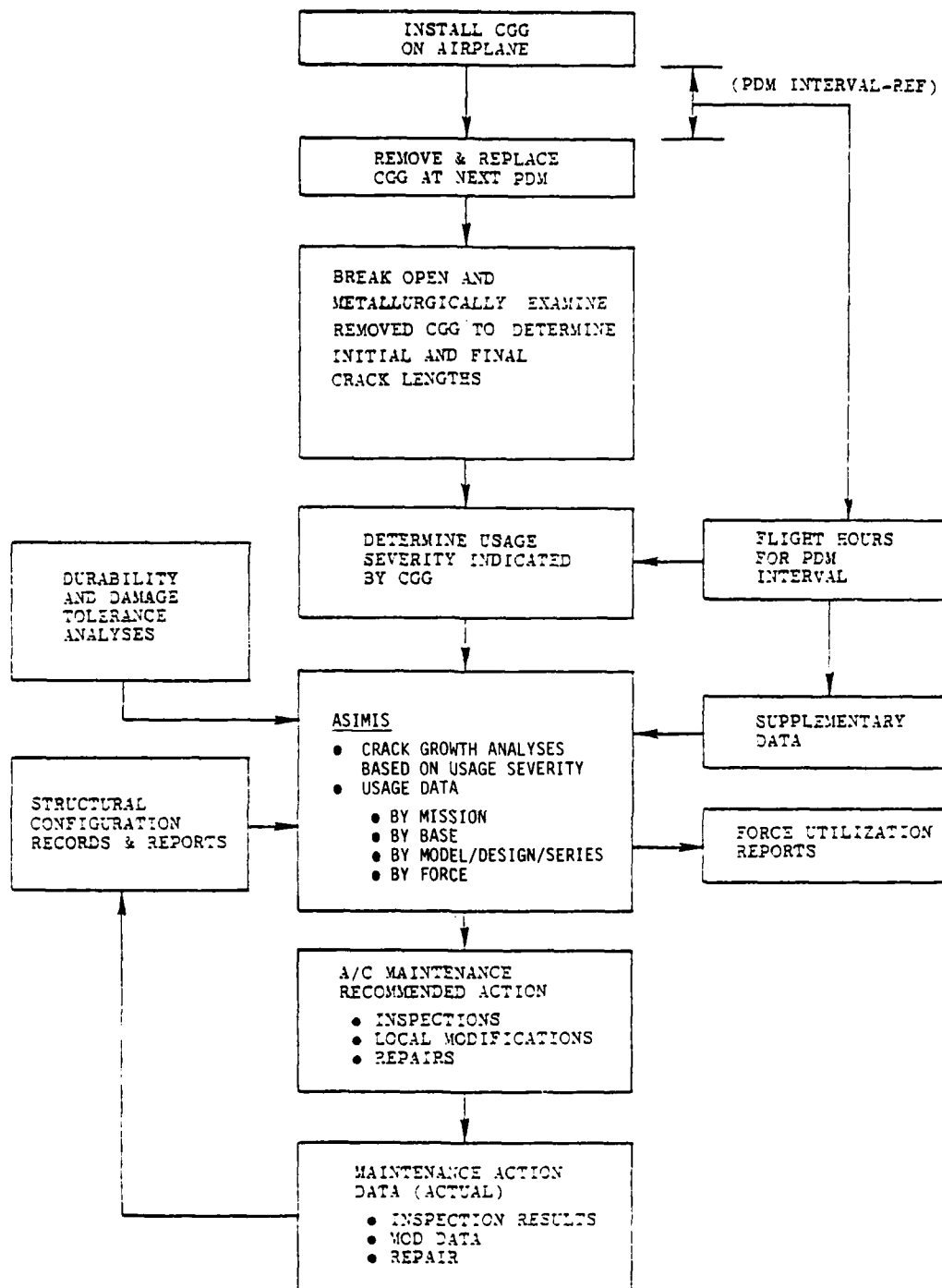
Figure 5-32. Crack Growth Gage - Flow Diagram.

location for each spectrum 'band' are analytically determined. (If implemented, about five levels of severity would probably be needed.) Corresponding crack growth characteristics of the CGG are determined by correlation analysis and experimental test data. The usage severity indicated by CGG response vs. actual airframe structural response forms the base for the IAT calculations. (Note that a usage increment such as flight hours is necessary as a base for the analyses.)

The method is affected by the sequence of loadings that result from various combinations of mission severity and mix. This spectrum sensitivity is shown schematically in Figures 5-33 and 5-34 The actual aircraft spectrum sensitivity will be different from the crack growth gage spectrum sensitivity (Figures 5-35 and 5-36) because of their different geometry effects. Since each individual aircraft will experience different usage, a "reasonable" relationship between the CGG spectrum sensitivity and the aircraft structure spectrum sensitivity is necessary to achieve a meaningful aircraft analysis from the CGG results. These spectrum sensitivity effects and also material and geometry variations between aircraft, between gages, and between aircraft and gages will all contribute to "scatter" in the analyses. Evaluations of the effects of variations such as these must be worked out for each aircraft series. The accuracy of the system is discussed in paragraph 5.2.6.7.

5.2.6.4   Data Collection

In the conceptual example, the crack growth gage is removed from the airplane at depot level inspection intervals and a new gage installed. The used gage is sent to the laboratory for determination of crack length. Note that the removal/reinstallation is necessary to keep the system going because the usage severity is based on the crack length measurements and the flight hours for the interval involved. Alternate methods for obtaining readings without removal of the crack growth gage are available, such as the Faxfilm replication method (Reference 5-2); using these on-the-airplane measurements would provide the necessary data in conjunction with the flight hours data for

5-112
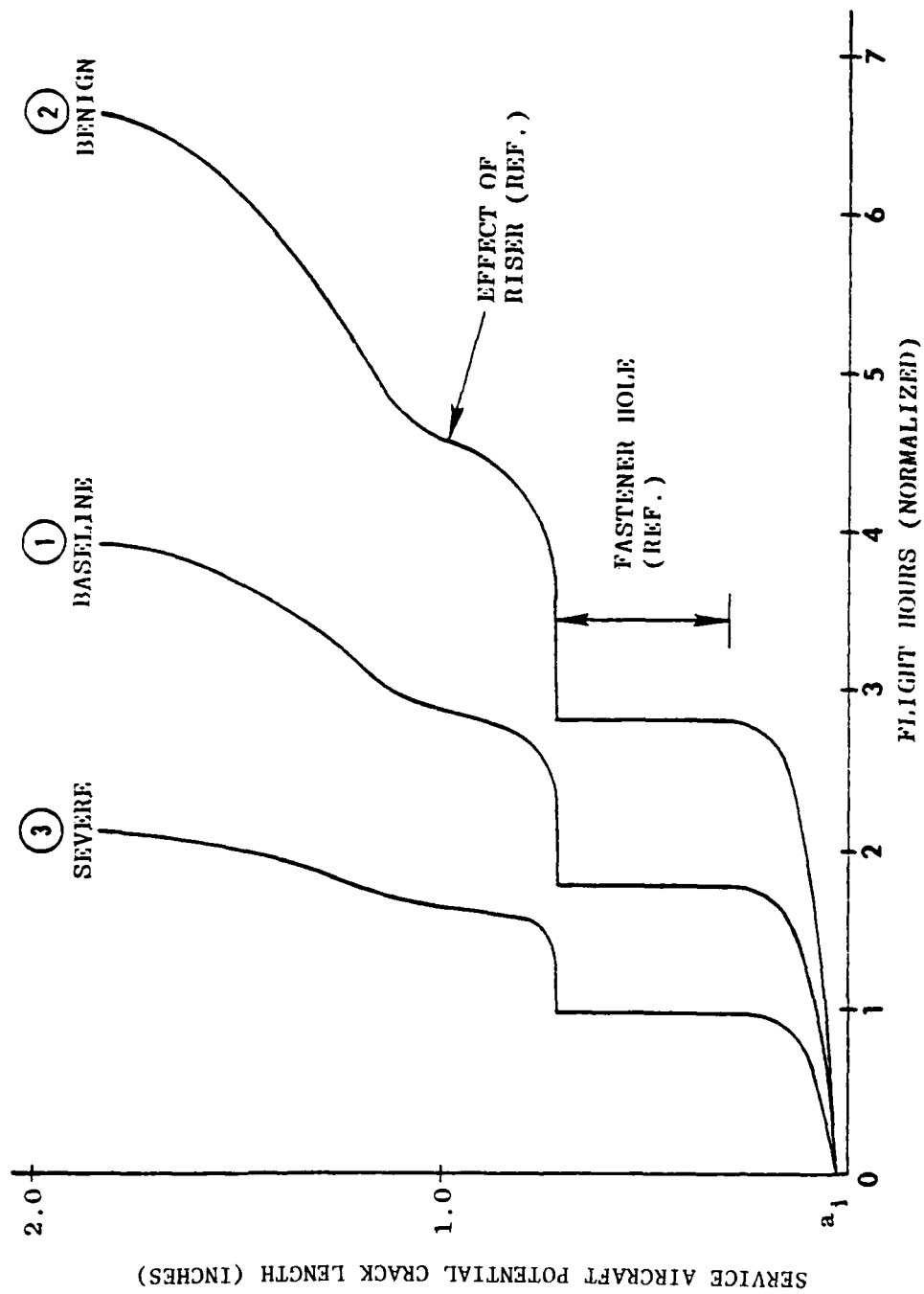
Figure 5-33.   Transport/Bomber Wing Structure Example Crack
Growth for Three Usage Severities.

EXAMPLE WING STRUCTURE
TOTAL CALCULATED CRACK LENGTH

FLIGHT HOURS (NORMALIZED)	○ SEQUENCE 1-1-1 (REF.-BASELINE)	△ SEQUENCE 3-1-2 (SEVERE-AVG.-BENIGN)	□ SEQUENCE 2-1-3 (BENIGN-AVG.-SEVERE)	◇ SEQUENCE * 1-2-3 (AVG.-BENIGN-SEVERE)
1	.08	.72	.06	.08
2	.72	.86	.72	.16
3	1.11	1.26	1.80	1.33

*Sequence of usages shown in Figure 5-33

NOTE: THIS PICTURE IS COMPLICATED ON SERVICE AIRCRAFT BY GEOMETRY EFFECTS DUE TO FASTENERS, RISERS, CHANGES IN THICKNESS, ETC., AND STRESS GRADIENTS.
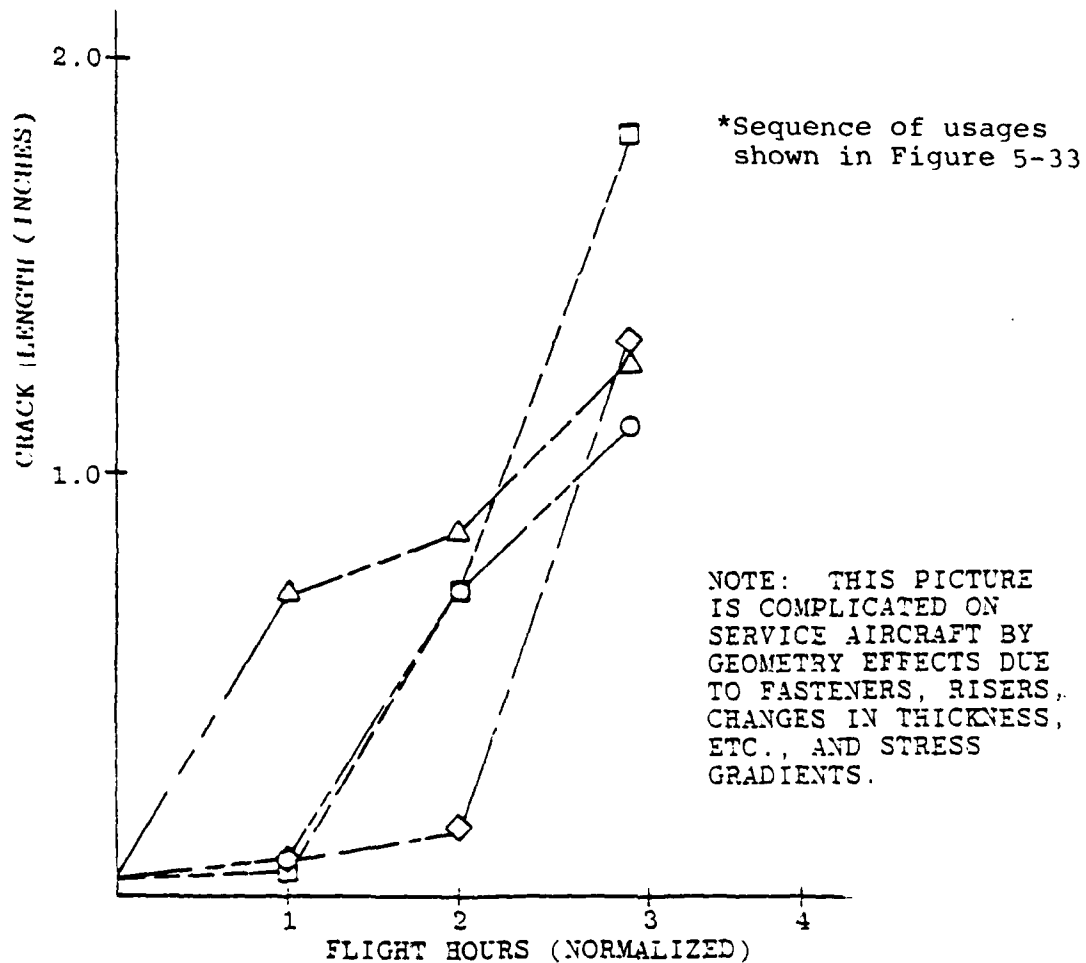
Figure 5-34. Example of Spectrum Sensitivity Effects.
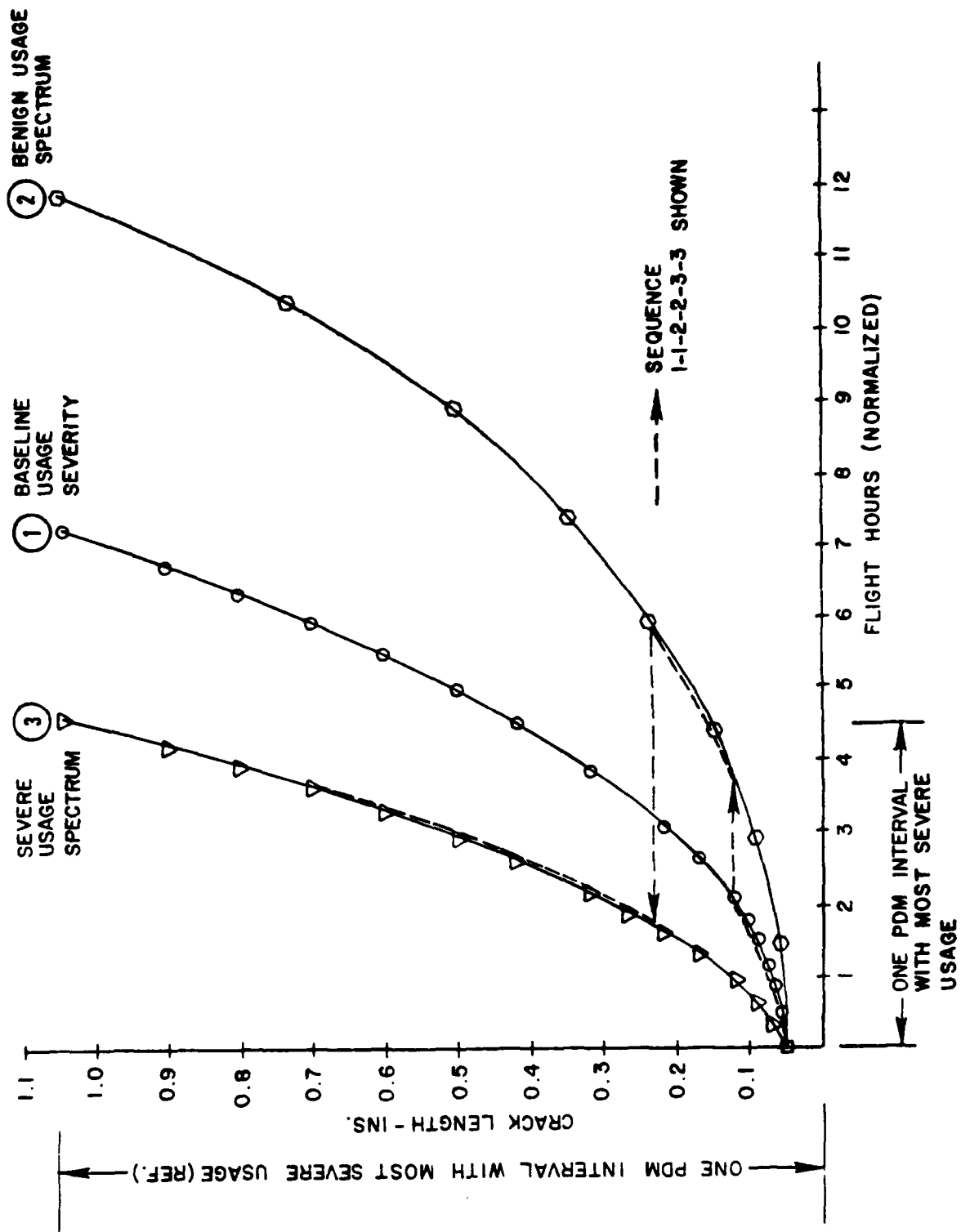
Figure 5-35. Crack Growth Gage Characteristics (Hypothetical Example).

CRACK GROWTH GAGE TOTAL CRACK LENGTH

TIME FRAME (ONE FRAME = 1 UNIT ON SH.1)	SEQUENCE 1-1-1-1-1-1 (REF) (BASELINE) ○	SEQUENCE 3-3-1-1-2-2 (SEVERE-AVG.-BENIGN) △	SEQUENCE 2-2-1-1-3-3 (BENIGN-AVG. SEVERE) □	SEQUENCE 1-1-2-2-3-3 (AVG.-BENIGN-SEVERE) ◇ *
1	.07	.12	.05	.07
2	.11	.28	.07	.11
3	.20	.43	.11	.15
4	.33	.62	.20	.21
5	.49	.80	.39	.41
6	.70	1.01	.66	.68

*Sequence of Usage Shown in Figure 5-35
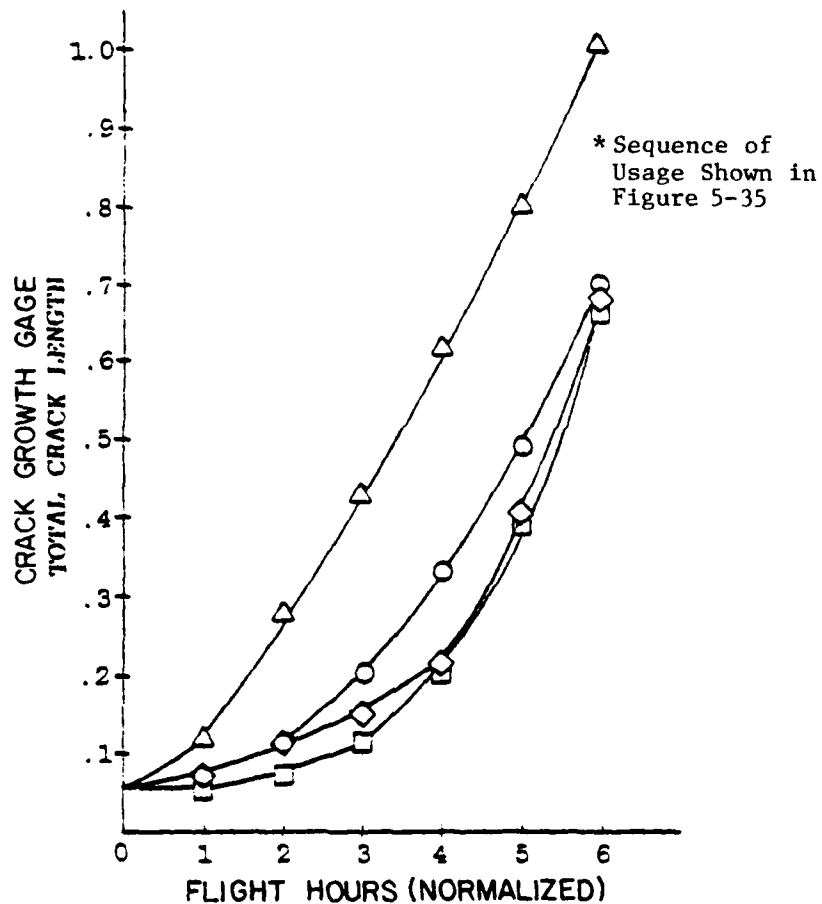
Figure 5-36.   Example of Spectrum Sensitivity Effects.

5-116

the same interval. However, the gages will be designed for one-interval crack growth under the most severe conditions (see paragraph 5.2.6.7) and therefore, should be replaced even if they can be read on the airplane.

5.2.6.5 Data Processing

No particular data processing problems are anticipated with the use of this usage indicator. Gap-filling consists of projecting the aircraft structural analytical crack length from its previous value through the timeframe to be gap-filled, using several variations of crack growth severity projections reflecting variations in usage severity.

The CGG concept described herein for transport/bomber aircraft requires an incremental usage increment such as flight hours in order to relate the usage severity as indicated by the CGG to the crack growth effects on structure for that severity and that amount of incremental usage (flight hours). Additional supplementary data are necessary in order to interpret the data. If the CGG indicates severe usage, it will be desired to determine if this indication is the result of higher than expected utilization of some particular mission type (training, logistics, aerial delivery, etc.); of a new type of utilization; or of a peculiarity in the crack growth gage response. Supplementary data are also necessary for other IAT usage descriptions. These data consist of the information presently obtained by the usage forms IAT.

5.2.6.6 Cost Elements

Table 5-14 lists the cost elements which may be anticipated for the crack growth gage based IAT system. The supplemental data requirements are the data presently acquired by the Usage Forms IAT System.

TABLE 5-14

IAT COST ELEMENTS FOR
CRACK GROWTH GAGE TRACKING

ELEMENTS	CGG	COMMENTS FOR CGG SYSTEM
INITIAL DESIGN AND DEVELOPMENT OF DATA ACQUISITION DEVICE AND SUPPORTING EQUIPMENT	X	
DESIGN OF HARDWARE SYSTEM FOR SPECIFIC AIRPLANE	X	INSTALLATION DETAILS ONLY
QUALIFICATION TESTING		
DESIGN OF SOFTWARE SYSTEM FOR SPECIFIC AIRPLANE	X	COMPUTER PROGRAM
T.O. FOR IMPLEMENTATION	X	
FAB. AND INSTALLATION OF DATA ACQUISITION DEVICE AND SUPPORTING EQUIPMENT (SENSORS)	X	
REPLACEMENT OF DATA ACQUISITION ELEMENTS: TRANSMITTAL TO ASIMIS	X	REMOVE AND REPLACE CGG'S
SPECIAL READING OF DATA ACQUISITION DEVICE	X	LAB MEASUREMENT OF INITIAL, FINAL CRACK LENGTH
DATA TRANSCRIPTION TO MAGNETIC TAPE	X	
COMPUTER ANALYSES OF DATA	X	
GAP-FILLING	X	COMPUTERIZED
SUPPLEMENTARY DATA ACQUISITION; TRANSMITTAL TO ASIMIS	X	
ADDITIONAL COMPUTER ANALYSES OF SUPPLEMENTARY DATA	X	
MANUAL CHECKING, ANALYSES, DEBUGGING OF COMPUTER OUTPUT	X	
REPORTS OUTPUT	X	
ON-BOARD SYSTEMS MAINTENANCE		
TEST EQUIPMENT FOR ON-BOARD SYSTEMS MAINTENANCE		

5.2.6.7 Accuracy (Realism)

An apparently ideal goal for a CGG system would be to develop a gage whose crack growth characteristics correlate precisely with the growth rate of the actual structure to which it is attached. If this were attainable, the final gage crack length could be set at 1/2 the flight time for the potential airframe crack to grow from the NDI detectable size a_{NDI} to critical length at limit load and repeat inspections on the actual airframe structure would then be made at the time required to achieve this growth interval (See Figure 4-4). If inspections did not disclose any cracking on the airframe (which is hopefully the case, since any structural cracks might be much less than the detectable limit) a new CGG would be installed and the process repeated until such time as airframe cracking was present (at which time repairs would be installed). This approach is consistent with DADTA slow crack growth approach to establishing safe-use intervals of flying based on NDI results and crack growth analysis. However, this ideal of a CGG which cracks at the same specific rate as the aircraft structure is not yet available with a simple gage attached to a complex structure. Also, a CGG designed in this manner would exhibit little crack growth at the short airframe structure detectable crack length (for example, 0.15" for a baseline C-141A). Therefore, if the gage or bonding were faulty, it might not be apparent for a long period of flying. The more desirable method described herein uses a Crack Growth Gage designed to crack almost (but not all the way) completely across the gage during one depot inspection interval under the most severe usage anticipated for the airplane. This maximum permissible crack growth sensitivity requires replacement of the gage at each inspection interval but provides increased accuracy in interpreting the data.

The "idealized" approach also depends solely on the proper operation of the CGG with respect to the airplane structure, i.e., no supplementary data are necessary. However, if rapid crack growth in the CGG is experienced, additional information would probably be sought prior to initiating special

inspection/maintenance action based solely on the CGG evidence. Conversely, if no crack growth were experienced in the CGG, the CGG or the installation would be considered suspect. Thus, the confidence in performing service aircraft inspection/maintenance action is related to the examination of supplementary data as well as of the CGG response. For Transport/Bomber aircraft, the CGG is not a stand alone IAT device but it can be a helpful adjunct to an IAT system such as the present usage forms system.

The approach described herein is the result of a conceptual evaluation of possible CGG methods. However, the accuracy of this system is dependent on all the relationships and scatter characteristics between the designed, fabricated, installed, and measured CGG and the aircraft structure it is being used to monitor. The accuracy (realism) is also dependent on the analysis method, which uses a PDM interval of data at a time and relates the "usage severity" indication of the CGG to the corresponding "usage severity" bands defined for the aircraft structure analysis.

Extensive study and testing would be necessary to establish the characteristics of a CGG based system. All in all, it appears that the best description of the CGG is that it is an attractive "activity indicator" with many matters unresolved in execution.

5.3 COMPARISON OF IAT METHODS

IAT methods are combinations of an analysis method and a data acquisition system which obtains the data required as input to the analysis. The methods that have been described consist of various combinations of four basic analysis methods to estimate potential crack length at a single location on the aircraft (cycle-by-cycle crack growth, parametric analysis from load exceedances, parametric analysis from flight conditions or mission parameters and the crack growth gage) and five acquisition systems to obtain the input data (usage forms, counting accelerometers, MSR, microprocessor, and CGG). All of the methods depend on parametric analyses to estimate potential crack length at the multiple critical locations on the airplanes.

To compare the tracking methods, criteria must be established to provide a basis for relative rankings. Among the prime candidate criteria are implementation costs and "accuracy" but the most meaningful criterion is the difference between the total IAT system cost and the dollars saved by implementing the system. To date, there have been no estimates of dollars saved through application of an IAT program and most estimates of IAT costs have been questioned. Therefore, an objective comparison of the methods is not possible at the present time and a selection of a method must be made on subjective grounds.

For example, probably the least expensive tracking system is based on the easily monitored parameter of total flight hours. At the other extreme might be a system based on strain gages at, say, 10 critical locations on the airplane from which cycle-by-cycle crack growth is computed. Which, if either of the systems is most cost effective depends entirely on the extra amount of money (if any) that can be saved by the complex system. Therefore, the choice of a tracking system in this application could not be dictated by total systems costs.

Experience with transport/bomber aircraft has shown that the current usage forms contain the minimum data that is required for force management of this aircraft class. Therefore, usage forms will remain as the data collection technique of choice until a microprocessor is developed which will provide this data and more and the judgement is made that any cost tradeoffs are justified.

In attack/fighter/trainer aircraft, the choice between tracking systems is not as distinct. It is generally conceded that tracking systems based on strain measurements are more accurate than those based on counting accelerometers. Therefore, if costs are comparable, the strain based system would be preferred, but relative cost rankings of these systems have not been consistent. Since the accuracy of a crack growth gage based system is determined by the repeatability of crack growth in different gages, this system is expected to be comparable in accuracy to a strain measurement system with cycle-by-cycle crack growth estimates at a nearby location. (Both systems would be subject to equivalent inaccuracies in estimating potential crack length at remote locations). Since it is generally conceded that the crack growth gage is the least expensive of the methods considered, it would appear that a crack growth gage based system would be preferred for attack/fighter/trainer aircraft. It must be noted, however, that the crack growth gage has yet to be demonstrated as a viable tracking device.

To aid in comparing the costs of the systems, Table 5-15. shows the cost elements for each system in a common matrix.

TABLE 5-15

COMPARISON OF IAT SYSTEMS COST ELEMENTS

| | COST ELEMENT APPLICABLE FOR SYSTEM | | | | |
ELEMENTS	USAGE FORMS	CA	MSR	MICRO-PROCESSOR	CRACK GROWTH GAGE
INITIAL DESIGN AND DEVELOPMENT OF DATA ACQUISITION DEVICE AND SUPPORTING EQUIPMENT				X	X
DESIGN OF HARDWARE SYSTEM FOR SPECIFIC AIRPLANE		X	X	X	X
QUALIFICATION TESTING				X	
DESIGN OF SOFTWARE SYSTEM FOR SPECIFIC AIRPLANE	X	X	X	X	X
T.O. FOR IMPLEMENTATION	X	X	X	X	X
FAB. AND INSTALLATION OF DATA ACQUISITION DEVICE AND SUPPORTING EQUIPMENT (SENSORS)		X	X	X	X
REPLACEMENT OF DATA ACQUISITION ELEMENTS: TRANSMITTAL TO ASIMIS	X	X	X	X	X
SPECIAL READING OF DATA ACQUISITION DEVICE		X			X
DATA TRANSCRIPTION TO MAGNETIC TAPE	X	X	X	X	X
COMPUTER ANALYSES OF DATA	X	X	X	X	X
GAP-FILLING	X	X	X	X	X
SUPPLEMENTARY DATA ACQUISITION; TRANSMITTAL TO ASIMIS		X	X		X
ADDITIONAL COMPUTER ANALYSES OF SUPPLEMENTARY DATA		X			X
MANUAL CHECKING, ANALYSES, DEBUGGING OF COMPUTER OUTPUT	X	X	X	X	X
REPORTS OUTPUT	X	X	X	X	X
ON-BOARD SYSTEMS MAINTENANCE		X		X	
TEST EQUIPMENT FOR ON-BOARD SYSTEMS MAINTENANCE				X	

5 4   IAT SYSTEM IMPLEMENTATION

The implementation of the IAT Program centers around three decisions: 1) the choice of a tracking analysis method; 2) the selection and procurement of a data acquisition system; and 3) the establishment of an interface between the IAT analysis and the maintenance scheduling activity.

5.4.1   Tracking Analysis Method

Three general categories of tracking analysis have been identified for the estimation of potential crack growth from IAT data. The first category is a cycle-by-cycle computation which utilizes a crack growth model of any degree of complexity. The second category utilizes exceedance curves from a period of operation to estimate crack growth for that period. The third category uses a parametric approach to define blocks of usage which can be related to increments of crack growth.

The cycle-by-cycle analysis method requires sequenced peak and trough stresses at each tracked structural location. The stress data must be provided from the IAT data collection/ processing system. If the IAT data collection misses data for some reason, the processing/analysis method must estimate data to fill the gap and the estimated data must continue the sequence. Analytically, the cycle-by-cycle is the most accurate crack growth estimation method since it can account for all known sequence effects. On the other hand, the complexity of this computation increases the computer time requirement to the extent that the cost of the cycle-by-cycle data reduction can be about an order of magnitude higher than for the other methods.

The exceedance curve method destroys the sequence of the data by summing it into the number of peaks (or troughs) in selected ranges of amplitude. Then, relying on the assumption that the sequence of peaks and troughs for the recorded period does not vary significantly from sample to sample, the exceedance curve is equated to a crack growth curve computed for a data sample having an identical exceedance curve but with a typical stress

sequence. By computing a series of crack growth curves for a family of exceedance curves, all of the calculations are made in advance and the increment of crack growth for a specific data sample is determined by iteration of the pre-calculated curves. This technique is very efficient in terms of data reduction time and cost. The accuracy depends on the variability of the mission and the effects of sequence for the particular stress amplitudes and structural locations.

The parametric approach to tracking was devised for tracking cracks based on flight condition and mission parameters. In general, the time spent in a given flight segment (defined by a combination of parameter values) is known. This time is equated to a given sequence of stresses or directly to an increment of crack growth by a parametric analysis. The parametric analysis is derived from a sample of data (such as the L/ESS) which records both the flight condition and mission parameters and the load parameters leading to the crack growth computation. This computation is about the same in complexity as the exceedance curve method and, since the load parameter is inferred rather than measured, is somewhat less accurate than the exceedance curve method.

Since the data sample can be very large, the cost of the IAT data reduction is a significant factor. In addition, the usefulness of the data to the structural maintenance scheduling activity is the real measure of the accuracy required. Therefore, the structural analyst must coordinate with the data reduction personnel and the maintenance planners during the selection of the tracking analysis method.

After the tracking analysis method is selected, software must be developed to process the recorded data into useful outputs for impacting maintenance planning. Since the recorded data content and format depends on the selection of the IAT recording system, the software can not be started until that selection is made. The primary factor in guiding IAT software development is the requirement that the software be eventually operated by the Air Force at ASIMIS. The contractor must coordinate with Air Force force management and ASIMIS personnel to determine acceptable software practices.

5-125

The Air Force is responsible for the planning and management of the IAT data gathering and processing. The contractor must present the recommended plans for tracking analysis and software development to the Air Force for approval.

5.4.2   Selection and Procurement of the IAT Instrumentation

A suitable IAT acquisition system must be selected which will fill the requirements of the tracking analysis method.

The only currently available IAT recording system which records a stress sequence is the Leigh mechanical strain recorder (MSR). The counting accelerometer (CA) is a commonly used IAT device which records exceedances of acceleration peaks. The CA regularly achieves a rate of return of 80 to 95 percent. For some systems, the CA counters are recorded after every mission and are associated with the mission type, takeoff weight, and takeoff configuration to permit more accurate load calculations.

Another commonly used IAT system is the usage form. This form is manually completed by a crew member who enters parameter values from the aircraft indicators during each mission segment along with pertinent events, such as landings and refuelings. Microprocessor recorders are expected to be able to record data and perform a significant amount of the data processing within the airborne instrumentation. The crack growth gage will provide a direct measure of potential crack growth at the monitored location.

The airframe contractor is to select the IAT recorder. The choice of any system not currently in operation involves a significant risk that the fleet usage will not be successfully monitored. The Air Force should provide funding to operationally test all promising new IAT concepts in parallel with a current IAT program. Such tests should use the Air Force operational support and ASIMIS processing support for a valid evaluation.

5.4.3 IAT Analysis and Maintenance Scheduling Interface

The concept that structural inspection and maintenance can be scheduled based on estimated crack growth is straightforward, but the mechanics of performing such a task are difficult to achieve. Maintenance engineers have not been accustomed to having analytical fracture mechanics information as input to making force management decisions. Structural engineers, on the other hand, may not understand maintenance and provisioning concepts, may not recognize the relation of structural maintenance to mechanical system maintenance, and may not be familiar with methods of obtaining needed structural inspection feedback information.

During the design of the tracking analysis method, the structural engineer should become familiar with the organization of the T.O.-6 technical order and the overall system maintenance plan. He should determine the feedback data that will be available and must plan to base his tracking program on this data. It is important that the paperwork of the tracking program does not impose significant effort at the maintenance level so that it can be cost effective.

The maintenance engineers, in preparing the maintenance program, must allow a mechanism to adjust structural inspection intervals and time compliance schedules. With some appropriate planning, the program can take advantage of the available usage information to improve safety and reduce costs. The maintenance engineers must communicate with the structures group before the technical orders are prepared to provide an effective interface.

SECTION 6

LOADS/ENVIRONMENT SPECTRA SURVEY (L/ESS)

SECTION 6

TABLE OF CONTENTS

SECTION 6
LIST OF FIGURES

SECTION 6

LIST OF FIGURES (Cont.)

SECTION 6
LOADS/ENVIRONMENT SPECTRA SURVEY (L/ESS)

The Loads/Environment Spectra Survey (L/ESS) function is concerned primarily with the collection and processing of usage data from aircraft performing representative operational flights. The L/ESS function does not directly impact decision making but rather provides a data base primarily for (1) checking assumptions previously made about the operational stress spectrum and (2) updating (when necessary) the durability and damage tolerance analyses (DADTA) and the force structural maintenance (FSM) plan. (On occasion, L/ESS data have also been used as a supplement in IAT programs but this is not considered to be a primary function.) Figure 6-1 presents a schematic of the L/ESS function through the requirement of the initial L/ESS. Updating the DADTA and FSM plan are not analysis requirements of the L/ESS function. However, developing the operational spectra and comparing the current operational spectra with the previous are clearly identified L/ESS functions. Monitoring for usage change can be an L/ESS function but may also be accomplished on the basis of other data.

According to MIL-STD-1530A, the "objective of the loads/environment spectra survey shall be to obtain time history records of those parameters necessary to define the actual stress spectra for the critical areas of the airframe." The prevailing connotation of this objective has been a large data set which contains statistical summaries of loads parameters and/or stresses stratified by flight conditions (mach number, weight, altitude, configuration) and mission description (mission type or segment, base of operation, command). Such data sets can also be used to summarize how the aircraft are being flown to generate the stress cycles which influence the potential crack growth at a critical location.

The following paragraphs describe the L/ESS requirements, discuss L/ESS methods, and summarize the implementation of the L/ESS function.
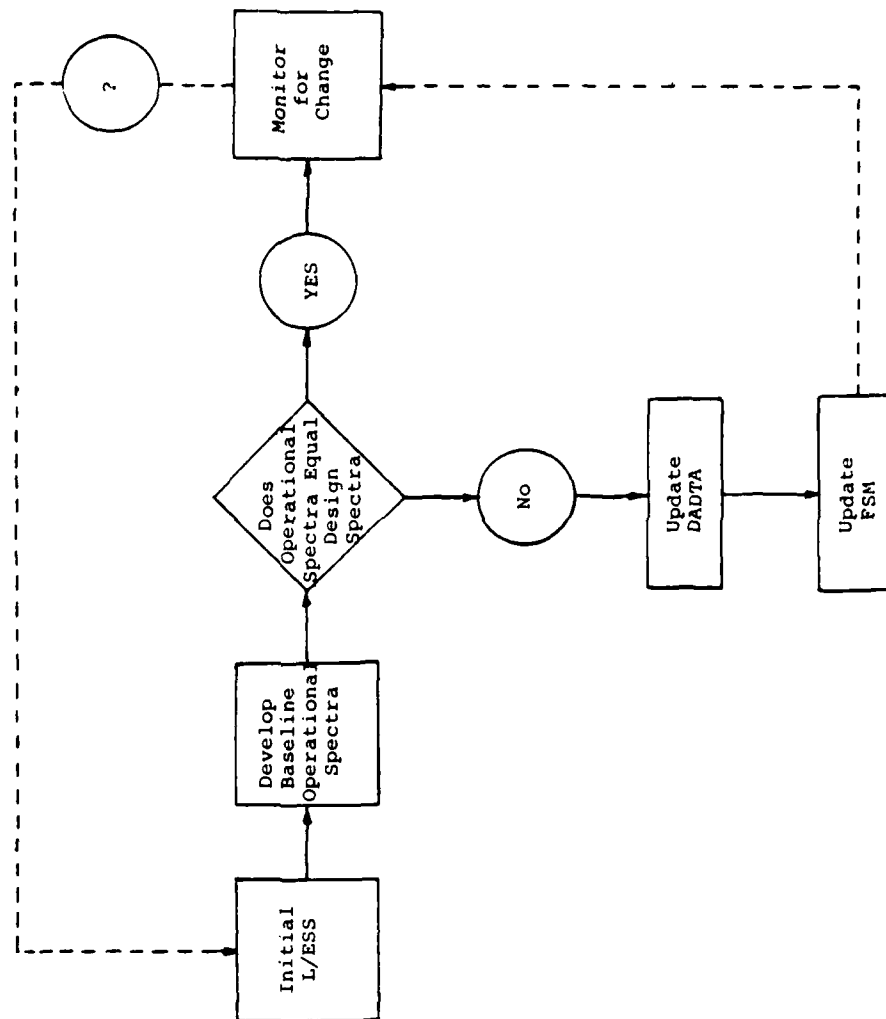
Figure 6-1. Schematic of Initial L/ESS.

6.1   L/ESS REQUIREMENTS

To meet the objective of the L/ESS function, operational usage data from a sample of the force is obtained and the operational baseline spectrum is formulated. This baseline spectrum is compared to the design spectrum and, if different, provides the input for updated analyses and the planned operational usage of a new FSM plan. Thus, the primary requirement of the L/ESS system is to provide appropriate usage parameter summaries in a format which will permit both of these analyses.

The following paragraphs will describe this primary requirement through discussion of various methods of using L/ESS data. In addition, other requirements of the L/ESS function are discussed including sample size requirements, usage change detection, design criteria data, and the duration of the L/ESS program.

6.1.1   Baseline Operational Usage

The initial force structural maintenance plan is based on estimated stress sequences that were derived from assumptions regarding operational usage of the aircraft. The assumptions concerned not only the magnitude of stresses that would result from predicted combinations of flight motion parameters but also the number and severity of maneuvers that would be performed to accomplish the design missions. (See paragraph 6.1.4 for further discussion of the generation of design spectra.) When the aircraft begins flying, data is collected which can verify the assumption of the analysis and, since reality generally disagrees with the original plans to some degree, provides the usage description for an update of the FSM plan.

In the damage tolerance approach to ensuring structural integrity, maintenance actions are triggered by potential crack lengths at critical locations. Since crack lengths are calculated from a knowledge of the stress history or sequence of stress peaks and valleys experienced by each

location, the operational usage environment can be considered as the stress sequences at all critical points in a structure. However, experienced and/or anticipated stress sequences at critical locations are generally not considered adequate for most L/ESS applications. Other factors which affect the application of L/ESS data include the following.

(a) At the time of selection of the instrumentation and analysis methods for the L/ESS function on a particular aircraft type, some of the critical locations may not be known. Therefore, it is generally necessary that the L/ESS data base be capable of providing stress sequences at locations not considered during the design of the data system. This consideration is generally met by recording various combinations of strain histories and "loads parameters." In this context "loads parameters" are defined as flight condition parameters from which aircraft loads (and stresses) can be calculated. Examples would include aircraft center of gravity motion parameters, airspeed, altitude, weight, aircraft configuration, etc. Paragraph 6.2.1 presents complete example listings for many aircraft types. The availability of the loads parameters permits calculation of stresses at any point in the structure.

(b) The frequency and magnitude of stress cycles depend on the intended missions of the force. Since it is reasonable to expect changes in the mix of planned missions and/or changes in the mix of mission segments which comprise the particular missions, the L/ESS data base should be capable of evaluating these changes. This requires the maintenance of data files with mission information associated with the recorded loads parameters and stresses. For example, a change in mission mix (percentage of each type of mission) can definitely cause a change in potential crack growth. However, if the stresses associated with each mission type are sufficiently characterized, the change can be evaluated on the basis of available data.

(c) For the usage forms based IAT systems (Transport/Bomber aircraft) the L/ESS data base is used to

estimate the crack growth rates as a function of crack length and time in flight segment or mission. While the L/ESS function always impacts the IAT function through the predicted crack growth curves of the DADTA, the interface of L/ESS and IAT is direct for the usage forms based systems. This direct interface can impose additional requirements on the L/ESS in the form of increased stress monitoring, stress transfer, and, possibly, sample size considerations.

(d) Although not a specific requirement of MIL-STD-1530A, operational mission descriptions are often produced as a data product of the force management system. These descriptions may include such data as numbers of flights and landings per time period and percent time in combinations of missions, mission segments, weight, airspeed, altitude, or configuration for each base of operation. Attack/Fighter/Trainer aircraft mission descriptions might also include normal load factor exceedance curves for missions, mission segments, or bases. The objective in producing the mission descriptions is to provide a basis for comparison of current with planned usage as defined by mission parameters. The mission descriptions are generally considered to be an output of the L/ESS. In the Transport/Bomber aircraft, however, the data required for a mission description are also contained in the pilot log form which is the basis of IAT. Such mission descriptions in Transport/ Bomber aircraft are derived as a part of the IAT function. In Attack/Fighter/Trainer aircraft, the tracking program does not, in general, contain mission data and if a mission description is desired, data from the L/ESS program or some other source would be required. Note that only a relatively small proportion of the total L/ESS data set is necessary to meet this objective.

To meet the general objectives of the L/ESS function and the specific data needs of each particular aircraft type, many different approaches have been devised. Figure 6-2 is a schematic displaying alternate approaches to the L/ESS function. For each particular stratification of usage (as
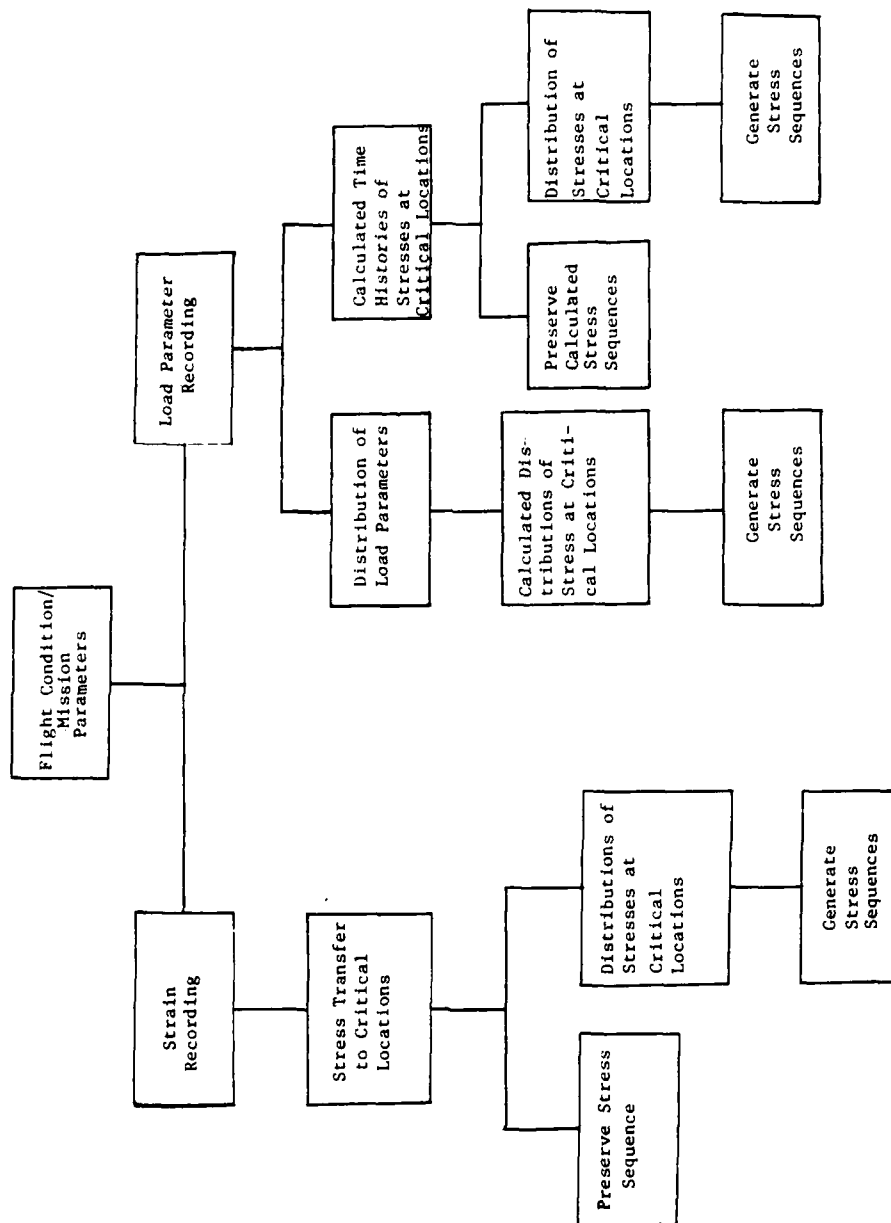
Figure 6.2. Schematic of Alternate Approaches for L/ESS Function.

defined by combinations of flight condition and/or mission parameters) which is to be characterized, strain at monitoring locations and/or load parameters are recorded on a continuous basis. Strain readings are converted to stress at the critical location and the desired output of stress sequences is either saved directly or the stress history is summarized by stress distributions which are later used to generate stress sequences. Note that the stress distributions permit comparison with design stress distributions and are in a more compact format for storage. Preserving the original stress sequences, guarantees that a representative ordering of stress peaks and valleys will be input to crack growth calculations. In the future it is expected that both processing methods will be used on at least some of the stress histories. An example of stress distributions is given in Figure 6-3. (Note: The examples of this paragraph are presented merely to demonstrate a few of the very large number of types and formats of L/ESS type data that have been used.)

All L/ESS programs to date have been based to an extensive degree on time history recordings of load parameters and load events. These data have been used to calculate time histories of loads and stress during periods of significant flight activity and these stress histories are treated like directly recorded stress histories. Figure 6-4 is an example of exceedances per 1,000 flight hours of wing pivot bending moment in a stratification of the flight regime of the F-111. Also shown on the figure is the exceedance curve for a design spectrum. The comparison of operational with design in this figure is in-conclusive due to the crossing exceedance curves at a mid value of bending moment.

Load parameter data are also reduced to joint distributions of coincident load parameter values when another value is peaking. Figure 6-5 presents distribution of values of normal load factor (n_z) and roll acceleration (p-dot) given lateral acceleration (n_y) peaks have occurred in defined ranges.
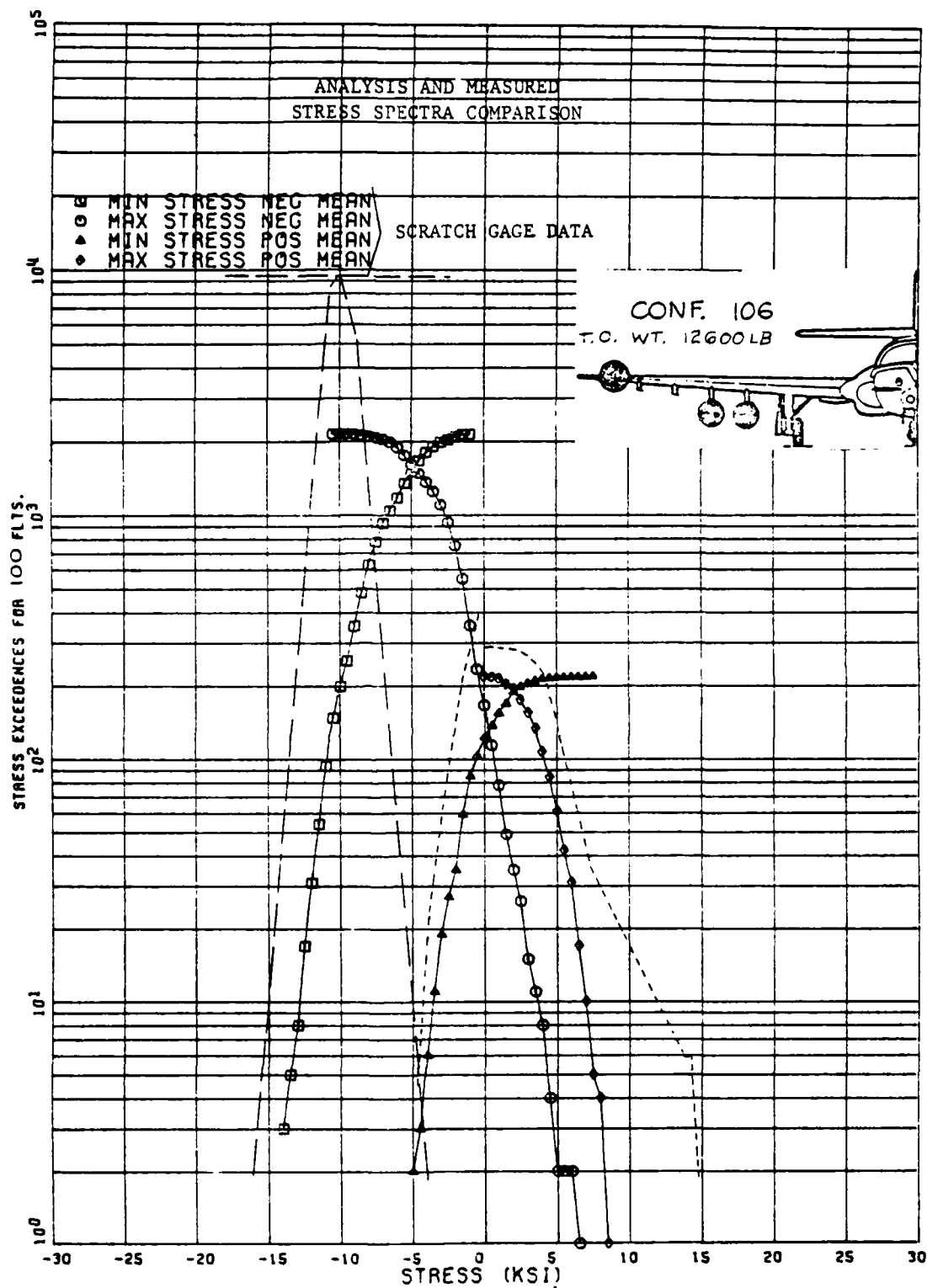
Figure 6-3. Example Stress Exceedances at WS91.5L for
Admin-Lt Mission Type. AFRES Usage-A-37B.

EC BS MC CF
2   3   11   1

EXCEEDANCES PER 100G HR OF EC-BS-MC-CF

---- 7.33G MAC SPECTRUM PHASE I AND II TRAINING

DOUBLE AMPLITUDE MOMENT -- MILLIONS OF IN-LBS
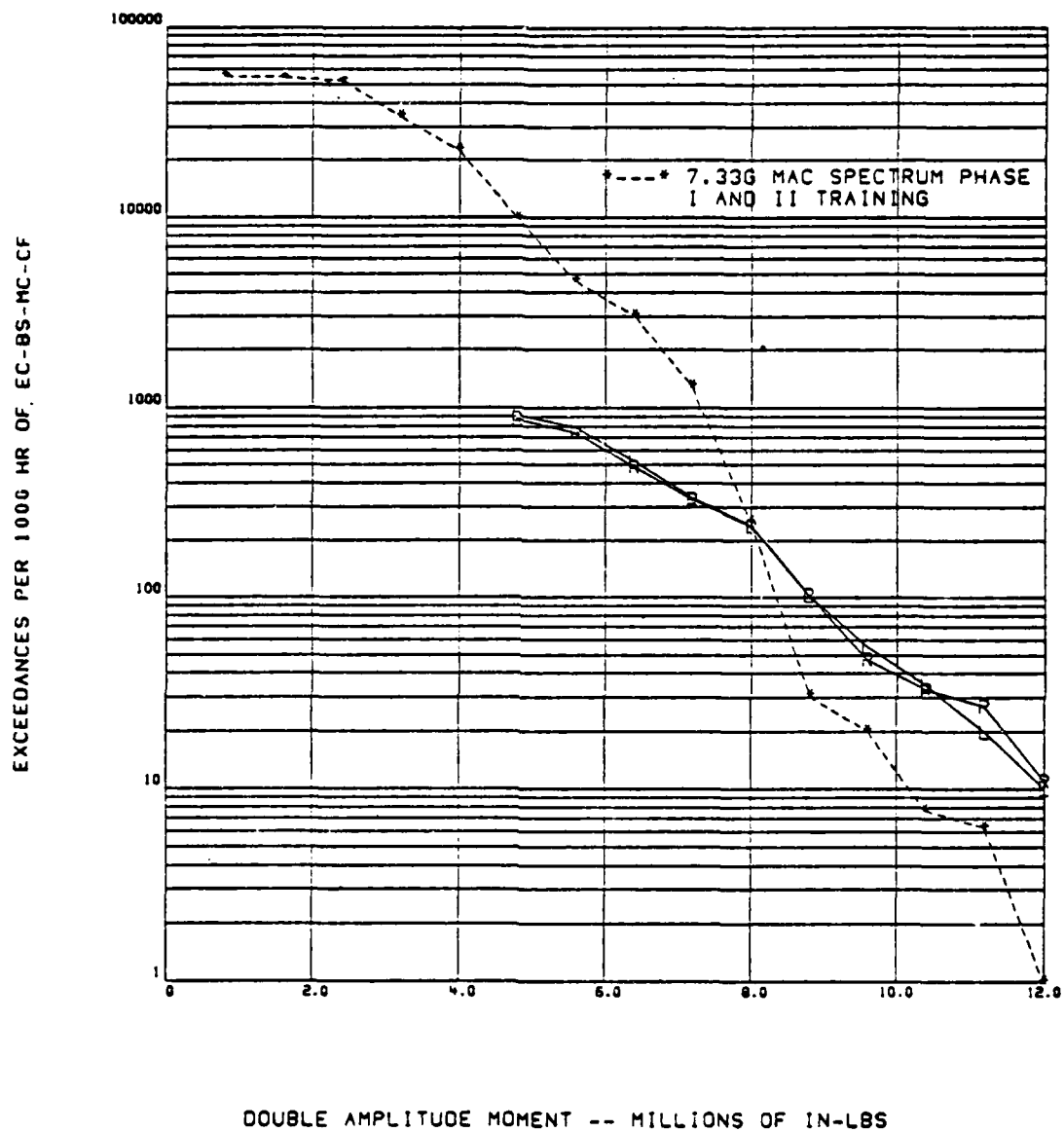
Figure 6-4.   Example F-111D Cumulative Frequency Distribution
              L/H and R/H Wing Pivot Bending Moment.

6-9

NY -0.7 TO -0.6
P-DOT

NZ	RANGE	-40	0	40	TOTAL
	A.0				
	6.5	1			1
	7.0				
	TOTAL	1			1

NY 0.2 TO 0.3
P-DOT

NZ	RANGE	-120	-80	-40	C	40	8C	120	TOTAL
	-0.5				1				1
	C.0			2	2	1			5
	1.0			3	2	1			6
	2.0							1	2
	2.5			2					2
	3.0								
	3.5	1		2	2				5
	4.0			2	2				4
	4.5		1	2		1			4
	5.0			1					1
	TCTAL	1	1	14	10	3		1	3C

NY -0.5 TO -0.4
P-DOT

NZ	RANGE	-120	-80	-40	TOTAL
	-0.5				
	C.0	1			1
	1.0				
	TCTAL	1			1

NY -0.4 TO -C.3
P-DOT

NZ	RANGE	-120	-80	-40	0	4C	TOTAL
	C.0			2			1
	1.0	1	1		1		3
	2.0						
	2.5			1			1
	3.0		1				1
	3.5						
	4.0		1				1
	4.5			1			1
	5.0			1			1
	TOTAL	1	3	4	1		9

NY 0.3 TO 0.4
P-COT

NZ	RANGE	-120	-80	-40	TCTAL
	C.0			1	1
	1.6				
	2.0				
	2.5				
	3.0				
	3.5				
	4.0			1	1
	4.5			1	1
	5.0		1		1
	TCTAL		1	3	4

NY -0.3 TO -C.2
P-DOT

NZ	RANGE	-120	-80	-40	0	40	TOTAL
	C.0			2			2
	1.0	1	3	11	5		2C
	2.0			1			1
	2.5	1	1	2	3		7
	3.0			4	1		5
	3.5		1	1	2		4
	4.0				2		2
	4.5		1	2	2	1	6
	TCTAL	2	6	23	13	3	47

NY 0.4 TO 0.5
P-COT

NZ	RANGE	-120	-80	-40	TCTAL
	2.5			1	1
	3.0				
	3.5				
	4.0			1	1
	4.5		1		1
	TCTAL		1	2	3

NY -C.2 TO -0.1
P-DOT

NZ	RANGE	-160	-120	-80	-4C	0	40	TOTAL
	0.0		3	4	35	4	3	49
	1.0	1	4	8	89	66	8	176
	2.0			2	14	14		30
	2.5				6	8	1	15
	3.0				11	3		14
	3.5				6	2		8
	4.0				2	2		4
	4.5				1	2	1	4
	5.0				1			1
	5.5					1		1
	TCTAL	1	7	14	165	102	13	3C2

NY 0.9 TO ABOVE
P-DOT

NZ	RANGE	-40	0	4C	TOTAL
	4.5				
	5.0		1		1
	5.5				
	TCTAL		1		1

NY 0.1 TO 0.2
P-DOT

NZ	RANGE	-80	-40	0	4C	80	12C	TOTAL
	0.0		6	12	4	1		23
	1.0	6	24	34	20	3	2	89
	2.0	2	14	13	4			33
	2.5		5	8		1		14
	3.0	1	6	3			1	11
	3.5	1	4	4				9
	4.0		4	4				8
	4.5		3	2				5
	5.0		2					2
	5.5							
	6.0		1					1
	TCTAL	10	69	80	28	5	3	195

ENTIRE NY RANGE
P-COT

NZ	RANGE	-160	-120	-80	-4C	0	4C	80	12C	TOTAL
	-0.5				1					1
	C.0		3	5	47	18	8	1		82
	1.0	1	6	18	127	107	30	3	2	234
	2.0			4	29	28	4		1	66
	2.5			1	17	19	1	1		4C
	3.0			2	21	7		1		31
	3.5		1	2	13	10				26
	4.0			1	10	8	2			21
	4.5			3	10	6	3			22
	5.0			1	5	1				7
	5.5				1					1
	6.0				1					1
	6.5					1				1
	TCTAL	1	11	37	280	207	48	5	4	543

Figure 6-5.   Example Trivariate Tables for Mission 1 Data
n_y Peaks for Bivariate of n_z and $\dot{p}$.

6-10

Such tables describe coincident values of the center of gravity motion parameters and when used in combination with distributions of flight parameters and loads events provide distribution of peak loads. Joint distributions are only obtained for reasonably coupled parameters and counts of load cycles are obtained from exceedances of a primary parameter such as vertical load factor, n_z. Figure 6-6 is a composite summary of the number of exceedances per 1,000 flight of various levels of incremental normal load factor ($n_z - 1$) for each of four types of missions. Figure 6-7 is a partial example of a set of tables which distribute the normal load factors with respect to weight, altitude, and airspeed ranges for the navigation and general type mission. Figure 6-8 displays mission parameter distribution for that part of a flight identified as the maneuver mission segment.

All of the L/ESS approaches of Figure 6-2 are shown leading to stress sequences at critical points. This emphasizes the primary objective of updating the potential crack growth curves of the DADTA, IAT, and FSM Plan. However, to date, there are no fixed analysis schemes for progressing from the recorded data to the stress sequences as essentially different methods have been derived for each aircraft type.

6.1.2   Sample Size Considerations

The loads, strains, flight condition and mission parameters which are usually construed as L/ESS type data exhibit considerable variability from flight to flight under routine operational usage. Under the best of circumstances, this variability makes it difficult to decide if the spectra in one period is different from that of design or a different period. Further, a typical spectra is defined in terms of a large number of distributions of the relevant load parameters for the flight condition and mission categorizations of interest. The combination of these complicating factors has inhibited the definition of criteria for identifying changes in operational spectra. Hence, there are no commonly accepted analytical techniques for testing
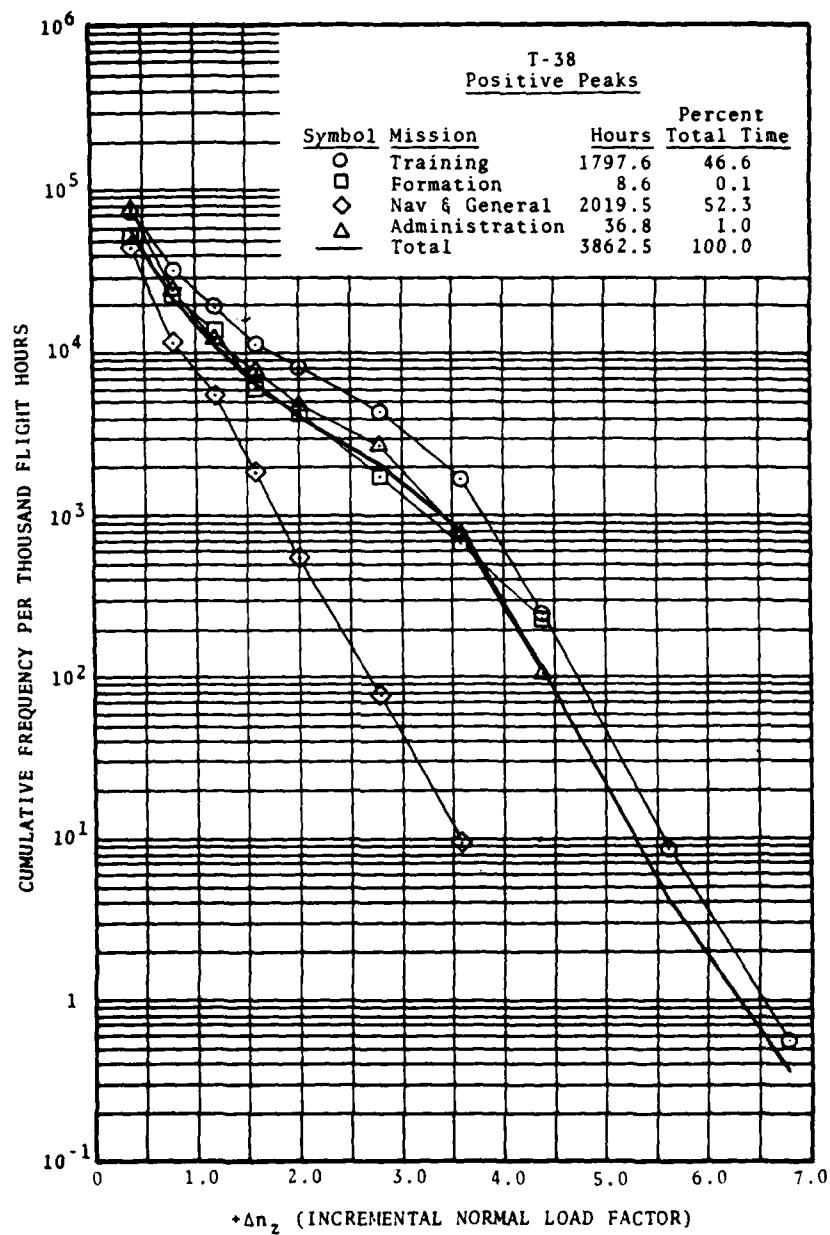
Figure 6-6.   Example Exceedance Curves of Positive
              and Negative n_z Peaks for Each Mission Type.

MAJ MIS TRAIN WEIGHT 7000 ALT 2000

VE AIRSPEED

	LESS	-1.8	-1.0	-0.6	-0.2	0.2	1.4	1.8	N_Z 2.2	2.6	3.0	3.8	4.6	5.4	6.6	7.8	TOTAL	TIME HOURS
LESS																		0.00
100																		0.00
150							2										2	.03
200						1	2		1								4	.03
250						1	2										3	.00
300																		0.00
350																		0.00
400																		0.00
450																		0.00
500																		0.00
550																		0.00
625																		0.00
700																		0.00
TOTAL						2	6		1								9	.06

MAJ MIS TRAIN WEIGHT 8000 ALT LESS

VE AIRSPEED

	LESS	-1.8	-1.0	-0.6	-0.2	0.2	1.4	1.8	N_Z 2.2	2.6	3.0	3.2	4.6	5.4	6.6	7.8	TOTAL	TIME HOURS
LESS																		0.00
100																		.05
150					2	46	125	15	1								189	.70
200						6	9	2									17	.38
250																		.02
300																		.00
350																		0.00
400																		0.00
450																		0.00
500																		0.00
550																		0.00
625																		0.00
700																		0.00
TOTAL					2	52	134	17	1								206	1.15

MAJ MIS TRAIN WEIGHT 8000 ALT 1000

VE AIRSPEED

	LESS	-1.8	-1.0	-0.6	-0.2	0.2	1.4	1.8	N_Z 2.2	2.6	3.0	3.8	4.6	5.4	6.6	7.8	TOTAL	TIME HOURS
LESS																		0.00
100																		.25
150					2	145	1114	101	9		1						1372	11.20
200						70	233	19	20	6	5						353	8.52
250					2	127	119	28	31	17	8						332	2.04
300						1	3				1						5	.05
350																		0.00
400																		0.00
450																		0.00
500																		0.00
550																		0.00
625																		0.00
700																		0.00
TOTAL					4	343	1469	148	60	23	15						2062	22.07

MAJ MIS TRAIN WEIGHT 8000 ALT 2000

VE AIRSPEED

	LESS	-1.8	-1.0	-0.6	-0.2	0.2	1.4	1.8	N_Z 2.2	2.6	3.0	3.8	4.6	5.4	6.6	7.8	TOTAL	TIME HOURS
LESS																		0.00
100																		.26
150						23	1130	4512	962	42	2						6671	38.10
200						10	1129	2822	1065	1361	304	61	1				6753	79.67
250						83	4555	7842	2152	2333	1007	277	13	1			18263	89.93
300					1	15	592	853	164	129	70	25	1				1810	5.55
350						2	8		1		1						12	.01
400																		0.00
450																		0.00
500																		0.00
550																		0.00
625																		0.00
700																		0.00
TOTAL					1	131	7368	16037	4343	3866	1383	364	14	2			33509	213.52

Figure 6-7.   Example Frequencies of n_z Peaks in n_z Versus Equivalent Airspeed Intervals by Altitude and Gross Weight for Each Mission Type.
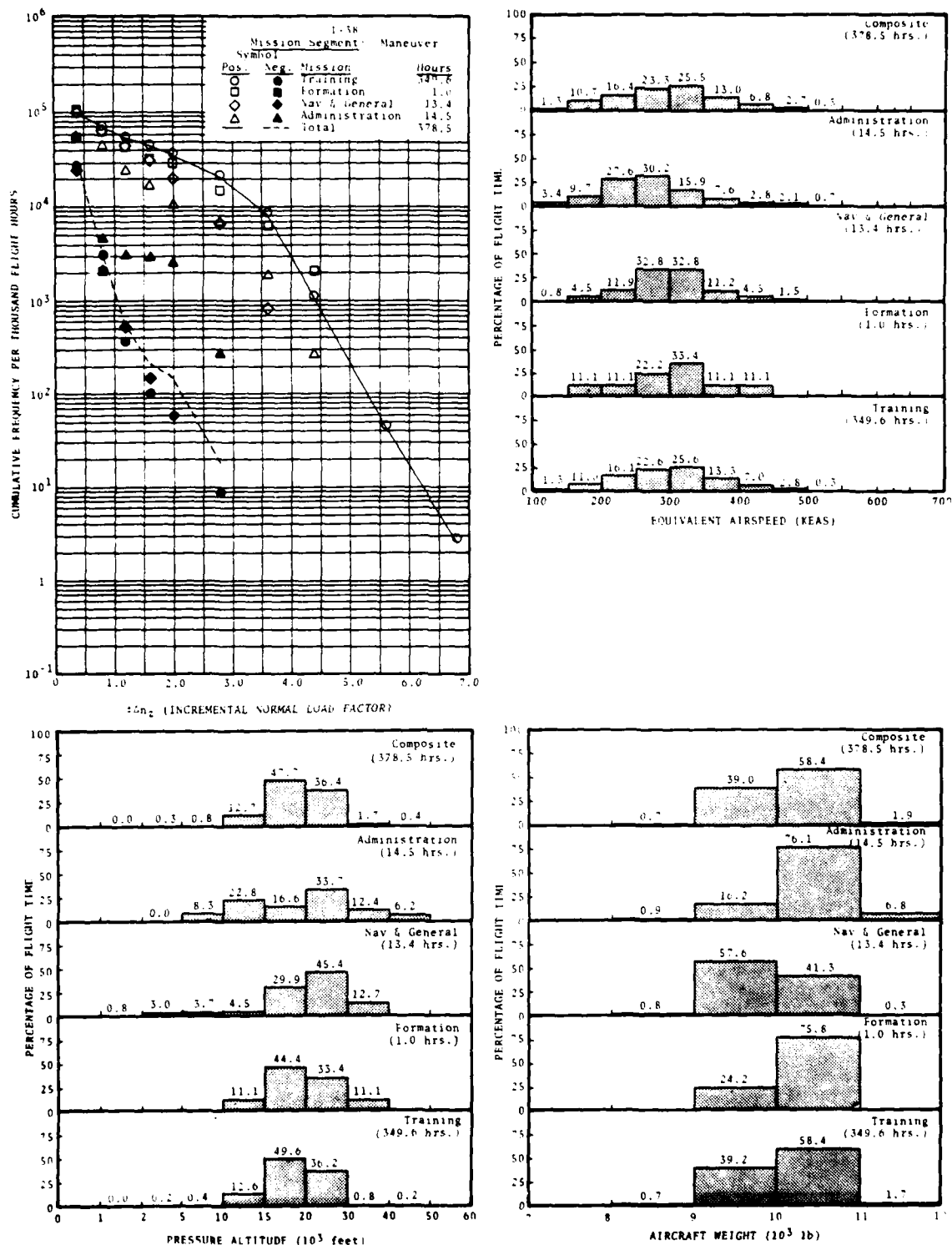
Figure 6-8. Example Maneuver Mission Segment: n_z Exceedance
Curves and Time Histograms of Equivalent
Airspeed, Altitude, and Weight by Mission Type.

6-14

equality of operational spectra (i.e., detecting changes) or for determining the required amounts of data to yield sufficient precision in the estimated spectra.

It is generally recognized that the L/ESS function is achieved by monitoring only a sample of all possible flights of the particular force of interest. It is necessary to assume that any particular sample of monitored flights is a random (representative, unbiased) sample for some population of interest. The economics of data collection for sampling operational usage dictates that the data sample will be obtained from the flights of a fixed set of instrumented aircraft. If the recorded flights are reasonably representative of total fleet operations, then the sample will be completely random and statistical inferences can be made without stratifying the population of all flights into sub-populations. However, it is common for certain mission types to be disproportionately represented in a sample of monitored flights (as determined by comparison with an independent data source). In this case, the monitored flights are representative only within stratifications of the population of all flights. Some example stratifications are divisions defined in terms of mission types, mission by base combinations, mission segment by mission design series, etc. Inferences made for a group of airplanes are then made by combining the results from individual stratifications. Note that the stratifications, if any, must be defined by an analysis of the operations to be sampled and the extent of the inferences to be drawn from the sample.

To develop a statistical approach to sample size determination and usage change detection in L/ESS, it is necessary to define a metric which is (1) relatable to design or previous operational usage spectra, (2) descriptive of severity of operational usage, (3) calculable as part of a routine L/ESS output, and (4) has known statistical properties so that inferences can be drawn regarding sample sizes and usage changes. One such metric that has these properties is the estimated potential crack growth during a flight given one fixed crack length at the start of all flights.

6-15

It can be shown that for many crack growth rate models the potential crack growth for a crack of fixed length is proportional to

$$X_i = \sum_{j=1}^{N_i} [f(\sigma_{ij})]^m \tag{6-1}$$

where

X_i is the random metric proportional to crack growth during flight i,

N_i is the number of stress cycles during flight i,

$f(\sigma_{ij})$ is a function of stress cycle j during

flight i defined by the crack growth rate equation, and

m is a parameter of the crack growth rate equation.

Since N_i is not necessarily large, the distribution of X_i will not be known in general (even though it is modeled as a sum of random variables). However, it is possible to empirically determine distributional properties of X_i over many flights and compare these with the equivalent properties from the design or previously used operational spectrum to test for changes in usage. Further, analytical sample size considerations could be approached from the viewpoint of determining the required number of flights to estimate the average X_i within a pre-specified degree of precision.

The activity metric defined by Equation (6-1) is directly proportional to the potential crack growth during a flight or flight segment of a crack of fixed initial length. Define this as the standardized crack growth rate metric. The standardized crack growth during any one flight or flight segment will be unknown but can be described as a random variable. Past experience with other such metrics indicates that the distribution of X will be highly skewed (to the large crack growth per flight side) with a large standard deviation as compared to the mean.

6-16

If the average of the distribution of standardized crack growth rates is taken as the measure of operational usage during a flight or flight segment, the objective of the L/ESS can be interpreted as estimating this average. Further, the precision of the estimate is determined by the number of sampled flights or flight segments so that given some estimate of the standard deviation of standardized crack growth rates a sample size can be predetermined to yield a desired degree of precision with a desired degree of confidence or, conversely, given a sample size the degree of precision can be estimated.

Several points should be made regarding the use of a statistical calculation of sample size. Recall that the inference is valid only over the population for which a random sample was obtained. If in a given L/ESS program, the data are considered to be random samples for each mission type, the mission characterization precision can only be defined in terms of the number of flights of each mission type. It should also be noted that it is not necessary to have the same precision for all stratifications. If, for example, certain mission types are far less damaging than others, less prediction could be tolerated in the standardized crack growth metric.

The above sample size concepts yield the number of flights or flight segments to be monitored to achieve the desired precision. It is assumed that sufficient precision in the standardized crack growth rate metric will also imply sufficient precision in the distributions of loads parameters that result from the monitored flights. The desired precision is achieved from a random sampling of all flights or flight segments within the population and is independent of the number of instrumented aircraft and/or the time period over which the flights are monitored. These decisions will have to be made on the basis of engineering judgment of the time frame during which decisions will be required. These decisions will also be influenced by the capture rate of valid data that can be expected for the particular aircraft and recording system.

MIL-STD-1530A also specifies that the "Air Force will also be responsible for ensuring that survey data are obtained for each type of usage that occurs within the force (training, reconnaissance, special tactics, etc.)" For some aircraft types, this requirement poses no particular problem as the usage need only be obtained for a few stratifications as defined by, say, mission types. For others, however, the usage is extremely diverse and there are so many mission design series that considerable care must be exercised in the allocation of monitoring equipment to aircraft. Further, it may also be necessary to monitor usage for considerably longer periods of time to obtain a reasonable degree of precision.

6.1.3 Usage Change Detection

In addition to defining the operational usage stress spectra, MIL-STD-1530A also indicates that the L/ESS function includes a proposed "method to be used to detect when a significant change in usage occurs to require an update in the baseline operational spectra." An optional approach to usage change detection is available if the appropriate data is available as part of the IAT program. Historically, usage

changes have been interpreted in terms of changes in exceedance distributions for some level of stratification of the total population of potential uses. Emphasis has shifted, however, to considering changes which can impact the monitoring of potential crack length to reach a pre-defined size. Thus, usage change detection should be defined in terms of parameters which occur at the interface between both the IAT and the FSM portions of force management.

Viewed in this light there cannot be a universal answer to usage change detection. In Transport/Bomber tracking, the basic element of data collection is the pilot log. With this source of data for tracking, potential crack growth rates by data block (loosely defined) are the essential parametric input as mission type and time in data block are directly monitored. Thus, the stress histories within the data blocks are the key parameters for feeding the tracking program and projections of crack growth are based on predicted amounts of time in data blocks. Contrast this situation with a counting accelerometer based tracking system in Attack/Fighter/Trainer aircraft in which the accelerometers are read monthly. In this type of program, potential crack growth and predicted crack growth are both dependent on assumptions regarding mission mix (weights and configurations) as well as severity of usage while performing the missions.

Operational usage changes are significant to ASIP only if they impact the durability and damage tolerance analysis. From the viewpoint of input to a DADTA, three types of usage changes are significant:

(a)   an initiation of a new mission or mission segment

(b)   a change in the magnitude of stress levels

(c)   a change in the exceedance rate of stress levels.

The stress environment in Transport/Bomber aircraft is governed primarily by mission usage which is monitored on pilot logs or turbulence which is a random property of nature. For this aircraft class a usage change would most probably be defined in terms of different mixtures of time in flight conditions or new mission segments. The former case is handled naturally by the pilot log tracking system with a recalculation required for the projection of potential crack length as a function of time. The latter change would require a characterization of only the new mission segment.

Attack/Fighter/Trainer aircraft usage changes would be defined only in terms of magnitude and frequency of occurrence of stress levels. Both of these types of changes could easily be detected in an IAT system based on stress measurements. If the tracking system were based on load factors, some form of supplementary data would be required to detect changes in the magnitude of stress levels. In particular, a general change in stress levels could result from performing maneuvers at different weights than in the original L/ESS characterization or from modifications to the aircraft which would change the stress response or pilot techniques during the performance of a maneuver. The potential for the latter change would be readily apparent to the ASIP manager. The former could be detected by a periodic review (survey) of operations. In either case, potential changes in usage could be detected without the operation of multichannel recorders in 10 to 20 percent of a force.

As noted earlier, there is a large degree of scatter in the stress environment of aircraft ostensibly flying the same mission. One result of this scatter is to mask the severity of usage in a period. To detect changes in usage from one period to the next for a particular stratification may require more data than is available from the sample of fleet operations. This is particularly true when the low capture rate of current L/ESS programs is considered. Therefore, it is doubtful that

usage change detection can be accomplished statistically from
L/ESS data. Rather, if it is accomplished from this data source,
it will be the result of unusual response at an unexpected time
(e.g., the introduction of a refueling mission segment) which
can also be detected from other sources.

6.1.4 Design Criteria Data

The AFR 80-13 requirement to provide structural
design criteria data has generally been interpreted to belong
to the L/ESS function of MIL-STD-1530A. The following
paragraphs briefly summarize the design criteria data requirements.

The design durability and damage tolerance analyses
of a new aircraft system are dependent on the sequence of
repeated loads the aircraft will experience during its lifetime.
To specify this sequence, it is necessary to have an estimate
of the number and severity of the load occurrences which will be
encountered. These are obtained from a combination of the
desired usage of the new aircraft and observed usage of current
similar aircraft.

The desired usage of a new aircraft system is
defined in terms of the expected frequencies of mission profiles
the aircraft will fly during its lifetime. Each profile defines
time histories of airspeed, altitude, and weight as well as
stores configurations, average fuel usage, number of pressurization
cycles and number of touch-and-go landings. This information
provides the basis for the flight conditions used to compute
the loads and the total time for each flight condition which
allows eventual determination of the number of load occurrences.
Figure 6-9 and 6-10 show one method of presenting mission profile
data.

The observed usage of current aircraft provides
load frequency and relative magnitude information. This is given
as the number of exceedances of a given load level, as indicated
by the peak load factor, n_z, for a reference flight time. The
reference flight time has usually been taken to be 1,000 hours

6-21

T-38 ATC MISSION PROFILE

MISSION: Basic Instrument   ENVIRONMENT: Air Training Command

PHASE	POWER SETTING	POINT	WEIGHT LB. INCR.	WEIGHT LB. GROSS	TIME MIN. INCR.	TIME MIN. TOTAL	SPEED TRUE	ALTITUDE FT. MSL
TAXI		START		12216				
		END	54					
TAKE-OFF	MAX	START		12162				
		END	342		2	2	155 KCAS	1000
CLIMB	MIL	START		11820			155 KCAS	1000
		END	350		8	10	350 KCAS	30000
CRUISE	1900 LB/HR	START		11470			350 KCAS	30000
		END	158		5	15	350 KCAS	30000
PRIMARY	2307 LB/HR	START		11312			350 KCAS	30000
		END	769		20	35	250-350 KCAS	26000 TO 32000
CRUISE	1850 LB/HR	START		10543			250-350 KCAS	30000
		END	154		5	40	350 KCAS	30000
DESCENT	PENETRATION PLUS PATTERN	START		10389			350 KCAS	30000
		END	1433		33	73	350 KCAS	
TAXI		START		8956				1000
		END						
		START						
		END						

Total Fuel Wt. = 3960 lb.
Internal Fuel Wt. = 3960 lb.
External Fuel Wt. = lb.
Pylon Tank Wt. = lb.

TAKE-OFF CONFIGURATION = BASIC
LANDING FUEL RESERVE = 700 lb.

Figure 6-9.   Sample Mission Profile Data.

T-38 ATC MISSION PHASE FLIGHT PARAMETER DISTRIBUTION

Mission	Percent Lifetime	Mission Phase	Phase Time Min.	Phase Time % Miss.	% Mix	Configuration	CW LBS	NUMBER of Flts
Basic Inst.	9.20	Take-Off	2	2.74	0.252	BASIC	11991	76
		Climb	8	10.96	1.008		11645	
		Cruise	5	6.85	0.630		11391	
		Primary	20	27.40	2.521		10928	
		Cruise	5	6.85	0.630		10466	
		Descent	33	45.20	4.159		9673	
Alter. Inst.	4.90	Take-Off	2	2.86	0.140	BASIC	11991	42
		Climb	5	7.14	0.350		11655	
		Cruise	5	7.14	0.350		11407	
		Primary	20	28.57	1.400		10938	
		Cruise	5	7.14	0.350		10471	
		Descent	33	47.15	2.310		9673	
Contact	30.80	Take-Off	2	3.03	0.933	BASIC	11991	280
		Climb	5	7.58	2.333		11655	
		Cruise	5	7.58	2.333		11407	
		Primary	20	30.30	9.334		10949	
		Cruise	5	7.58	2.333		10493	
		Descent	29	43.93	13.534		9684	

Figure 6-10. Sample Mission Profile Data.

for convenience. Figure 6-11 shows a sample n_z spectra. Current practice then combines the observed n_z distribution with the mission profile and desired life information to produce a table of occurrences at various n_z levels for each mission. Since each peak n_z value represents a load level, the total predicted number and relative magnitude of the loads for the life of the aircraft are now known.

This information is not sufficient to accurately compute the magnitude of the loads. Still required are the other motion parameters which are coincident with the peak n_z. These include pitch, roll, and yaw angular velocities and accelerations, lateral and longitudinal linear accelerations, and the airspeed, altitude, weight data from the mission profiles. The aircraft motion parameters are typically recorded during L/ESS programs but the data have not generally been processed in a format convenient to the design criteria requirement. Aircraft motion parameters have been found to be conveniently summarized in bivariate tables of n_z or n_y and coincident values of the other parameters. Multivariate data sets can then be reconstructed by computer simulations.

The design criteria data requirement can easily be met by L/ESS program if the appropriate output is made a part of the L/ESS function. Further, since sufficient data will be collected during the initial L/ESS to characterize the operational usage of a new aircraft, this quantity of data will be sufficient to specify the joint distributions of motion parameters for design criteria purposes.

6.1.5   Duration of the L/ESS

MIL-STD-1530A is ambiguous about the duration of the L/ESS program. Beginning with the first production airplanes, the requirement is clear that the L/ESS will continue for three years or until one design life of valid data has been collected. After this initial L/ESS and the DADTA update,

6-24
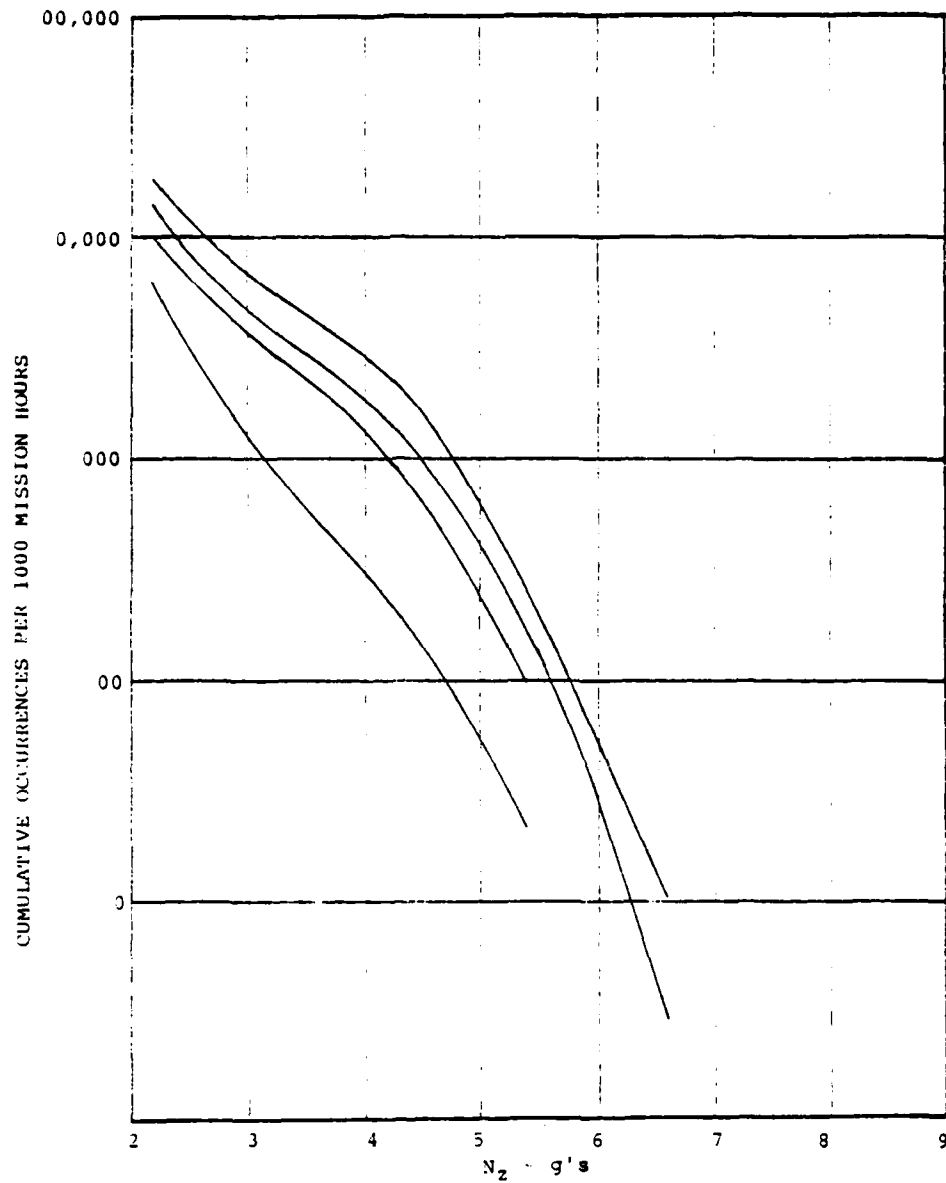
Figure 6-11. Sample Normal Load Factor Spectra.

however, the requirement is to detect usage changes and, if
necessary, generate new baseline operational spectra. These
latter requirements have been interpreted to imply that the L/ESS
will continue with objectives of detecting usage changes and
having available a data base for a new DADTA if a significant
change is detected. In view of the large costs associated with
the complex process of continuously recording and reducing the
multichannel data of L/ESS programs, the potential benefits
of these objectives should be reviewed.

Paragraph 6.1.3 indicates that the objective of
usage change detection not only can be met by data from other
sources but also may be more efficiently met by the other
data sources. Since the L/ESS system is very expensive as
compared to a system designed around IAT, aircraft records or
periodic questionnaires, it is also more cost effective to use
the other data sources.

Beyond the requirement of usage change detection,
the objective of a continuous L/ESS is to have available a
start of a data base for analysis. This data base has four
potential uses:

(a) a significant usage change will require a new
set of load sequences on which to base the DADTA;

(b) an unexpected or unusual structural problem
at a base could lead to an analysis of the usage at that base;

(c) the monitoring of mission descriptions;

(d) the development of design criteria type data.

If a change has occurred that is of sufficient magnitude that a
new DADTA will be required (e.g., a major structural modification),
it will also be of sufficient magnitude that data from before the
change will not be mixed with data after the change. In this
case a new L/ESS would be planned and initiated so that L/ESS
data would be available for the new load sequences. If only a
new mission segment is introduced, only that segment need be

monitored and all other representations would be as originally determined.

The second and third potential uses are quite similar and are a valid reason for continuing an L/ESS type program for A/F/T aircraft. (For T/B aircraft, this information is better obtained from the IAT data base.) However, these objectives would be met by processing only the normal acceleration, airspeed, and altitude data. The time and effort required to collect and process the other parameters are not justified for these uses.

Finally, the data for the design criteria requirements can be met during the initial L/ESS. This requirement does not justify a continuing L/ESS program.

Assuming the existence of an adequate initial L/ESS, an IAT program, and a periodic examination of auxiliary data that would indicate usage changes, a continuing L/ESS program is not necessary, in general. If it is judged important to monitor operations for a particular force, this function can be accomplished by processing only the data from three channels. Therefore, the L/ESS should operate only for the initial characterization of operational usage and for special characterizations during the life of the aircraft. A continuous L/ESS may be required for some aircraft types.

6.2 L/ESS METHODS

The objective of the L/ESS is to obtain a representative sample of data which defines the operational stress spectra of the force. A review of current L/ESS programs indicated that the L/ESS function is achieved in a variety of ways with the analysis techniques being dictated by the loads philosophy of the airframe manufacturer. Since the final use of the L/ESS data product is determined by the particular DADTA and IAT Program with which it interfaces, it is not appropriate to define separate L/ESS methods. Representative summary descriptions of in-use methods are presented as examples of various L/ESS methods.

The basic decision in the selection of L/ESS methods is the selection of monitoring loads parameters, local strains, or some combination of the two. This choice is related to the complexity of the aircraft equations of motion and tends to be resolved in accordance with local engineering judgment. Given the type of data to be monitored, the key decision is a choice between reducing the data into a summation of time and events in data blocks or into a computed sequence of stress peaks and valleys at critical locations. Beyond these basic differences, the variations in L/ESS methods are due to the details of data reduction, processing, and analysis.

This paragraph presents L/ESS methods through discussions of parameter selection and recording methods, and a review of existing data processing and analysis methods. A discussion on data-processing is presented in Appendix C.

6.2.1 L/ESS Parameter Selection

The parameters to be monitored during the L/ESS are determined to provide the necessary input to durability and damage tolerance analyses and individual aircraft tracking programs. Parameter requirements are airplane specific. To provide an indication of the parameters that were used in past programs, Figure 6-12 presents the parameter lists for aircraft which use the MXU-553A and AN/ASH-28 multichannel recorders. Similarly, Figure 6-13 presents the C-5A parameter list (with added details) which is based on the Malfunction, Detection, Analysis and Recording System (MADARS)

Figure 6-12.   Parameter List (MXU-553/A and AN/ASH-28 Multichannel Recorders).

Parameter	A-10	A-37	B-52	C-130	C/KC-135	C-141	E-3	F-5E/F	F-15	F-16	F-100	F-105	T-37	T-38	T-43
ECU Type	68	68	66	67	66	67	67	68	—		68	68	68	68	67
Airspeed	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
N_z	x	x	x	x	x	x	x	x	x	x	x	x	x	x	(1)
N_y	x	x				x	x	x	x	x	x	x	x	x	
N_x	x	x	x	x	x				x	x					x
Altitude	x	x	x		x	x	x	x	x	x	x	x	x	x	
Fuel Flow		x		x	x			x	x	x	x	x	x	x	
Roll Rate	x	x		x	x				x	x					
Angle of Attack									x	x					
Pitch Rate	x	x				x	x	x	x	x	x	x	x	x	
Yaw Rate	x	x		x		x	x	x	x	x	x	x	x	x	
Roll Accel.				x						x					
Elevator	x	x		x		x	x	x	x	x	x	x	x	x	
Rudder	x	x		x		x	x	x	x	x	x	x	x	x	
Aileron	x	x							x	x	x		x		
Speed Brake	x								x	x					
Time	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Fuel Totalizer			x		x	5	5								
No. of Strains	1	1	4	6	4	x	x	1		1	x		1	1	x
Flaps				x		x	x	x		x	1			x	
Nose Gear Steer.				x											
Rate of Climb									x						
Ground Speed						x	x			x					
Engine RPM				x											
Cabin Pressure				x											
Event Codes 1	O	F	E	AC	E	AC	E	C	U	E	O	(2)	D/E	P	E
2	B	G	Q	E	T	E	Y	C	AC	AC	E	(2)			
3	E	H	R	AD	S	U	Z		AE	C	F	(2)			
4	F	I			U		AA		AF		G	(2)			
5	G	J			V		AB				H	(2)			
6	H	K					T				J	(2)			
7	I	L					V				K	(2)			
8	A	M									L	(2)			
9	B/N	E/N												D	

Event Codes

A	Store Drop (left)
B	Store Drop (fus)
C	Store Drop (coded)
D	Takeoff
E	Weight on Wheels
F	Store Drop-Pylon L1
G	Store Drop-Pylon L2
H	Store Drop-Pylon L3
I	Store Drop-Pylon L4
J	Store Drop-Pylon R1
K	Store Drop-Pylon R2
L	Store Drop-Pylon R3
M	Store Drop-Pylon R4
N	Refueling
O	Gunfire
P	Ground Cals
Q	Boom Contact
R	Flaps Retract
S	Flaps Extend
T	Autopilot On
U	Speedbrake Deployed
V	Refuel Door Open
Y	6 RPM Antenna Rotation
Z	1/4 RPM Antenna Rotation
AA	Reserve Tank Valve (L)
AB	Center Tank Pumps (L)
AC	Ldg. Gear Down
AD	Ramp Door Open
AE	Weapon Count
AF	Config. Identification

Note: (1) Both gust and maneuver N_z derived by analog filter on N_z
      (2) Information not obtained

6-29

RECORDED PARAMETER	UNITS	MADAR NAME	MADAR P-CODE	RESOLUTION	RECORDING RANGE	SAMPLE RATE (NO./SEC.)
Flap Position	Deg.	Flap	02	1.848	0 to 40	1
Pressure Altitude	Ft.	PR Alt	06	444.4	0 to 50000	1
Mach Number	-	MACH	08	0.01	0 to 1	20
Vertical Load Factor	-	VA/CG	12	0.038	-1.0 to +3.5	10
Right Aileron Position	Deg.	Ailer	24	0.504	+15 to -25	
Ground Speed	Kts.	VG	28	1.575	0 to 150	2
Wing Stress:						
Upper Panel (WS577)	psi	Uppnl	43	655.2	-29040 to 22960	20
Lwr Aft Beam (WS197)	psi	Last 2	47	680.6	-22375 to 31625	20
Lwr Aft Beam (WS330)	psi	Last	58	504.0	-22325 to 17625	20
Upr Aft Beam (WS330)	psi	Uast	60	630.0	-20430 to 29570	20
MADAR Time	HMS	ZULU	09	N/A	N/A	1
LIIRP Discrete Word:						
Aerial Refueling	N/A	AR	11	N/A	0 or 1	Once Per 5 Sec
Aerial Delivery	N/A	AD	13	N/A	0 or 1	Once Per 5 Sec
Touchdown Switch	N/A	TD/SWT	15	N/A	0 or 1	Once Per 5 Sec
Spoilers Deployed	N/A	Spoil	17	N/A	0 or 1	Once Per 5 Sec
Inbd'd Thrust Rev. Deployed	N/A	IN TR	19	N/A	0 or 1	Once Per 5 Sec
Outb'd Thrust Rev. Deployed	N/A	Out Tr	21	N/A	0 or 1	Once Per 5 Sec
Terrain Following Active	N/A	TF	23	N/A	0 or 1	Once Per 5 Sec
Pitch Autopilot Act.	N/A	Plt Eng	25	N/A	0 or 1	Once Per 5 Sec
ALDCS Active	N/A	ALDCS	27	N/A	0 or 1	Once Per 5 Sec
Compressor Speed	%	N2	N/A	0.23	0 to 110	1
Fuel Flow	lb/hr	FF	N/A	67.4	0 to 16000	1
Throttle Angle	Deg.	TA	N/A	0.51	0 to 80	1

Figure 6-13. C-5A L/ESS Parameter Description.

	Parameter	Recording Rate	Signal Source
1.	Mach Number	1 sps	CADC, M, 36A (R3-D)
2.	Pressure Altitude	1 sps	CADC, Hp, 1AC
3.	Outside Air Temperature	1 sps	Total Temperature Indicator
4.	Wing Position	1 sps	Wing Sweep Transmitter
5.	Acceleration, Z Axis - (load factor)	30 sps	
6.	Acceleration, X Axis - (load factor)	10 sps	*Three Axis Linear Accelerometers
7.	Acceleration, Y Axis - (load factor)	15 sps	
8.	Roll Rate	15 sps	
9.	Yaw Rate	15 sps	Flight Control Sensor Set
10.	Pitch Rate	15 sps	
11.	Flap Position	15 sps	Flap Position Transmitter
12.	Landing Gear Position	1 sps	From Main Landing Gear
		every other second	Uplock Switch
13.	Sink Speed	5 sps	*Sink Rate Radar
14.	LH Horizontal Tail Position	15 sps	LH Horizontal Tail Transmitter
15.	RH Horizontal Tail Position	15 sps	RH Horizontal Tail Transmitter
16.	Rudder Position	15 sps	Rudder Position Transmitter
17.	Fuel Flow, Right Engine	1 sps	RH Engine Fuel Flow Indicator
18.	Fuel Flow, Left Engine	1 sps	LH Engine Fuel Flow Indicator
19.	True Angle of Attack	5 sps	CADC, α, 5A
20.	Right Outboard Spoiler Position	30 sps	*RH Spoiler Transmitter
21.	Left Outboard Spoiler Position	30 sps	*LH Spoiler Transmitter
22.	Left Main Landing Gear Strut Pressure ⊛	1 sps	*Pressure Transducer
23.	Right Main Landing Gear Strut Pressure ⊛	1 sps	*Pressure Transducer
24.	Nose Landing Gear Strut Pressure ⊛	15 sps	*Pressure Transducer

sps ~ sample per second   *~Peculiar to MCR Installation
⊛ ~ Pneumatic

Figure 6-14.   F/FB-111 Multiple Channel Recorder Parameters.

recorders and Figure 6-14 presents the F/FB-111 parameter list. The recorders will be discussed in detail in paragraph 6.2.2.

The timing of MIL-STD-1530A requirements tends to force the selection of L/ESS parameters before the analysis has identified critical structural locations and loading conditions. Consequently, parameters may be selected as insurance for the possibility that a particular loading condition might later prove to be significant. During L/ESS data analysis it may be determined that many extraneous parameters were recorded. However, most force management engineers are unwilling to eliminate parameters, even though not definitely required, due to the possibility of a still undiscovered structural problem.

6.2.2   L/ESS Instrumentation

The large number of parameters generally required of the L/ESS leads to the necessity of using a digital multichannel recorder. There are four multichannel recorders currently in use. These are the MXU-553, AN/ASH-28 and A/A24U-6 Recording Sets and the MADAR System. One three-channel recorder, the A/A24U-10 is in use on the F-4, but three-channel recorders are not expected to be used to meet the L/ESS function on any other aircraft. Figure 6-15 identifies the aircraft with current L/ESS programs and the type of system, number of instrumented aircraft, and the number of recorded parameters.

The following paragraphs present a description of the four multichannel recorders that are in use. In addition, a discussion is presented on the potential use of a microprocessor/ recorder system and the use of only strain measurements to accomplish the L/ESS function.

6.2.2.1   MXU-553/A Recording Set

The most commonly used multichannel recorder is the CONRAC Corporation MXU-553/A Recording Set (installed in 15 aircraft types). The recorder samples up to 26 input signals at frequencies from 1 to 30 per second as directed by a signal conditioning unit and writes the digital values on

Aircraft	Recorder	Fleet Size	No. With Recorders	No. of Parameters
A-10	MXU-553	773*	16	15
A-37B	MXU-553	200	23	21
B-52	MXU-553	349	11	20
C-5A	MADARS	77	8	24
C-130	MXU-553	711	60	20
C/KC-135	MXU-553	751	66	20
C-141	MXU-553	271	27	20
E-3A	MXU-553	40*	7	7
F-4	A/A24U-10	1798	213	3
F-5 E/F	MXU-553	91	5	13
F-15	A/ASH-28	749*	150*	22
F-16	MXU-553	2292	17%	22
F-100	MXU-553	200	8	20
F-105	MXU-553	531	7	
F/FB-111	A/A24U-6		71	24
T-37	MXU-553	700	11	13
T-38	MXU-553	920	9	11
T-39	MXU-553	142	14	15
T-43	MXU-553	19	5	8

*Planned

Figure 6-15. Current L/ESS Data Collection Programs.

6-33

tape in a 240-word data format which holds all the samples taken in one second of elapsed time. The data is recorded in a large, removable tape cassette and can be retrieved at ASIMIS by inserting the tape cassette into a special playback device which transcribes the data onto a computer tape. Several "documentary data" values such as aircraft serial number, mission type, weights, date, etc., can be entered via thumb wheels in the front of the recorder or in a remotely located panel. Four different signal conditioning unit configurations are currently available for use in various classes of aircraft or types of recorded parameters.

The ground crew or the pilot is required to gain access to the recorder before each flight to read the percentage of tape remaining and to enter the documentary data via the recorder thumb wheels. On earlier programs the access to the recorder required so much effort that the crew generally neglected to perform this task. On the F-16 aircraft, recorder access has been designed to reduce the effort so that crew members can perform this task quickly.

The ground crew is required to remove the tape cassette after about 12 hours of MXU-553/A operation and to replace it with a fresh cassette from supply. The spent cassette is shipped to ASIMIS where it is transcribed to a computer tape, erased and rewound, and returned to supply for reuse or repair as necessary.

The equipment has some built-in test capability; however, most of the recording system diagnostics are performed during data processing at ASIMIS and the base is notified of each malfunction and the probable cause. The mechanic removes the malfunctioning unit and requests a replacement from supply. Spares are stocked at the central location and a considerable amount of time elapses between ordering a replacement part and receiving it at the base.

The general specifications of the MXU-553/A
are shown in Figure 7-16. The MXU 553 signal conditioning accuracy
is ±0.8 percent of full-scale and the resolution is 8 bits binary
(or 1/256 of full-scale). Typical transducer accuracies range from
±0.5 percent of full-scale to ±3 percent of full-scale depending
on type and cost of the transducer.

Most systems are able to obtain usable data
from about 20-30 percent of the total flight time. Most of the
unusable data is the result of transducer malfunctions. The major
problem which keeps the usable data percentage down is the delay
from the time of malfunction until detection and subsequent
corrective action. It is not uncommon for this time to exceed six
months during which period the recorder continues to produce unusable
data. USAF management policy should assign sufficient priority to
the L/ESS data collection effort to achieve improvement in the
percentage of usable data.

6.2.2.2   AN/ASH-28 Recording Set

The CONRAC AN/ASH-28 is identical to the
MXU-553/A in its basic operation except its components are packaged
especially for the F-15 installation and the tape capacity is
increased to 25 hours of F-15 operation.

Unlike the MXU-553/A, the AN/ASH-28 system
has self-contained transducers for measuring angular rates about
the three principal axes and linear accelerations along these axes.
A special digital terminal interfaces with the aircraft central data
bus from which the documentary and several other parameters are
derived. For the F-15 aircraft, the documentary data is entered
in the cockpit via the navigation computer keyboard so the pilot
can perform this function during his preflight cockpit check.

GENERAL SPECIFICATIONS

SIGNAL DATA RECORDER

Volume	10" W x 10" D x 8" H maximum
Weight	25 pounds including cartridge & accessories
Record Time	15 hours minimum
Cartridge (Size)	8-1/4" W x 8-19/32" D x 1-7/32" H
Cartridge (Weight)	3.75 pounds
Tape Length	1200 feet, 1/2 inch magnetic tape
Number of Tracks	9 tracks utilizing 1 record head
Record Method	Multi-track serial biphase encoded, 8 data bits plus parity/character
Power	115 Volts 400 Hz 100 watts maximum 28 VDC 20 watts maximum
Documentary Encoder	24 independent data inputs utilizing thumbwheel switches
Density	1000 characters/inch (9 bits/character)
BIT	Isolate failure to Converter/Multiplexer, Recorder or Documentary Data Encoder
Dropouts/Dropins	Less than 1 in 500,000 bits

CONVERTER/MULTIPLEXER

Volume	6" W x 8" D x 5-7/8" H
Weight	7.5 pounds maximum
Sampling Rate	1-30 samples maximum per parameter, 240 samples per second total
Number of Parameters	26 parameters maximum
Analog Inputs	DC, AC, strain guage, potentiometric
Discrete Inputs	28 VDC
Active Filters	0 to 1, 2, 3, 4, 6, 8 Hz band-pass
Accuracy	±0.8% F.S. over environmental range
Resolution	8 bits binary
Power	Supplied by Signal Data Recorder
BIT	Automatic and manual pushbutton

Figure 6-16. General Specifications of the MXU-553/A Recording System.

6-36

6.2.2.3 A/A24U-6 Recording Set

The F/FB-111 multiple-channel flight load recorder system consists of a Dynasciences Corporation A/A24U-6 airborne signal data recorder set, source transducers and associated wiring. The recorder receives signals from the source transducers; applies appropriate signal conditioning, filtering, and sampling; converts the measurements into binary values and digitally records the data on a 30-track magnetic tape. The tape is housed in a removable magazine.

The recorder operates continuously while the airplane is on internal electrical power and the access door to the auxiliary ground power receptacle is closed. Capacity of the magazine is approximately 25 hours. Twenty-four parameters (data items) are recorded. The resolution of the recorded data is 6 bits binary (1/64 of full-scale).

After a magazine has been installed for 25 flight hours or six flights (five for FB-111As), Air Force personnel remove it from the airplane and send it to a specific signal data converter (SDC) facility where the data measurements are transcribed onto "field data tapes". Operable magazines are subsequently returned to the sender for reinstallation.

A flight usage card is prepared by Air Force personnel for each F/FB-111 flight. These cards provide mission identification and description information needed for analysis of data and other service life management analysis work.

Additional information about the F/FB-111 MCR system is presented in USAF T.O. 1F-111A-21-12 ("F-111 Service Usage Recorder Program --Data Collection and Reporting") and T.O. 1F-111(B) -2-1-2 ("FB-111 Service Usage Program -- Data Collection and Reporting"). The former covers application of the MCR system in F-111A/E/D/F airplanes while the latter covers FB-111A airplanes.

6.2.2.4   MADAR System

With the constantly improved capability
of electronic recording equipment and the increased interest in
recording operational data from engines, electronics, and other
aircraft subsystems, it is likely that future recording systems
would record other information in addition to structural usage
data.   In fact, it is also likely that the structural data might
be only a minor part of the intended purpose of the recording
system.

The C-5A L/ESS signal acquisition/recording
system is a modified Malfunction, Detection, Analysis and Recording
(MADAR) system with other hardware and sensors added as required.
The system was modified for the C-5A Service Loads Recording Program
(SLRP) and is used with only minor modification in the L/ESS.   The
basic MADAR is a digital recording system that was designed to
assist the flight crew in inspecting the characteristics of airplane
Line Replaceable Units (LRU) and subsystems for either degradation
or failure while in flight or on the ground.   To perform the SLRP,
and therefore the L/ESS, MADAR components underwent modifications
that resulted in greater memory capacity within the digital com-
puter, a faster recording rate, and additional signal conditioning
to handle the new SLRP data signals.

The analog signals output by various
sensors are detected, amplified, filtered, converted and/or other-
wise "conditioned" as required within the signal conditioning
components of the MADAR.   Signal conditioning results in the opera-
ting range of most data parameters being normalized to ±-5.0 vdc
except for a few parameters which are normalized to a lesser voltage.
These conditioned signals are then sampled according to an order or
sequence controlled by the on-board digital computer.   The number
of times per second that a particular data signal is sampled is
called the "sample rate".   Typical sample rates are 1,2,5,10, or
20.   Each sampled value is digitized, that is, converted from

volts to "counts" (21 millivolts) and compared with the last recorded value of the same parameter. If the new value differs from the last recorded value by more than a prescribed "half window" number of counts, then the new digitized value is recorded, otherwise not. The amount of change necessary to cause recording is called the "resolution" of the data channel. By definition, a resolution is equal to the half window value plus 1 count. This recording concept is sometimes called a "moving window" compression technique. The result is data compression, i.e., large quantities of analog data can be represented by small quantities of recorded data. The data which meet recording requirements pass into a buffer and then eventually onto the magnetic tape of the MADAR data recorder.

Several minor system modifications were incorporated for the C-5A L/ESS. The on-board computer program software was modified to acquire and process an ALDCS (Active Lift Distribution Control System) on-off signal using test points which were already accessed by the MADAR. The internal processing of the thrust reverser signals was updated to be more reliable.

A total of 24 flight recorded parameters are utilized in the C-5A L/ESS. These include ten "SLRP-type" parameters, MADAR recorded time, the life history recording program (LHRP) discrete word and 12 engine trend type parameters. The "SLRP-type" parameters are a portion of the specially processed and encoded MADAR parameters devised specifically for the SLRP program. They form the bulk of the recorded data upon which all C-5A L/ESS operations are based. The C-5A L/ESS discrete word combines 8 discrete or event type parameters previously recorded for SLRP and one new discrete channel, ALDCS operate mode, into a single recorded message. This message is written on tape once every 5 seconds and again whenever a change in one of the event channels occurs. The result is a set of nin discrete channel time histories (which can be more effectively edited and interpreted than the previously presented discrete channel data) compressed into a single channel of recorded data. MADAR recorded (ZULU) time and the 12 engine trend parameters (3 for each engine)

are basic MADAR system parameters used initially for other MADAR applications. They were adopted without change for the SLRP and therefore are retained on the C-5A L/ESS. The engine parameters are fuel flow, compressor speed and throttle angle for each of the four engines.

The MADAR system is maintained in the field. The maintenance diagnostics function of MADAR is flight-essential and is maintained on a priority basis but the structural parameter equipment is not flight-essential and thus maintained accordingly. The recorder has built-in test capability. In addition, a portable programmable test device is available at the bases for diagnosing MADAR equipment malfunctions.

6.2.2.5   Microprocessor-Based System

The term microprocessor-based recording system is applied to a variety of concepts which use a microprocessor in the signal conditioning circuitry. These devices have a significant amount of computing capability and use solid state memory to reduce cost and improve reliability. Although several prototype microprocessor recorders are currently being tested, this type of recorder has not yet seen wide use in force management.

Potentially, an on-board microprocessor can perform the entire data acquisition and analysis function but the complexity of the process including data editing will probably preclude this level of on-board processing. It is anticipated, however, that microprocessors will be designed and flight tested which can perform system checking, indicate malfunctions, and compress data by eliminating the non-significant parameter time histories. Such a device could be used in conjunction with current multi-channel recorder systems and would be expected to improve the quality and quantity of flight recordings as well as save computer time in the ground processing of the data in accordance with current analysis methods.

If a new microprocessor based recorder is developed, the frequency of data retrieval will depend on the extent to which this airborne computation capability is used to reduce data storage requirements. Most proposed systems are aiming for data retrievals about once each month. A mechanic will be required to carry a portable data retrieval device to the aircraft where he will connect it to the recorder and dump the recorder memory contents into the playback. The data retrieval device will also perform extensive diagnostic checks on the recorder. The data from the playback unit will either be recorded on a small tape cassette for mailing to ASIMIS or will be sent to ASIMIS via telecommunication lines.

6.2.2.6 Strain Only Systems

For some aircraft applications, the L/ESS function can be accomplished by recording strain histories or sequences of strain peaks and valleys at several locations in a sample of the aircraft. This approach is currently being implemented on an L/ESS update for the A-7D aircraft. The recording system for this approach could be based on several mechanical strain recorders if it is not necessary to correlate the stress peaks and valleys from the different locations. Another approach is to design a simple microprocessor based system which receives, as input, strains from electronic strain gages. The microprocessor can provide simple editing checks and error diagnostics. It can either compress the strain histories for later processing at a central computer facility or identify peaks and valleys and tabulate in a joint distribution interval to the recorder. If the compressed strain histories are maintained, the addition of mission data makes this method essentially equivalent to a general microprocessor based L/ESS system. If only joint distribution of peak stresses are saved, no data will be available for correlating stress spectra with usage data.

6.2.3 L/ESS Data Processing and Analysis Methods

The L/ESS data processing is required to handle large volumes of multiparameter data collected during a relatively small sample (5-20 percent) of the total fleet operation. The MXU recorders generate about 0.86×10^6 data samples per hour of operation, but the number of significant load excursions on an average flight varies from 40 to 1,000. The problem is to determine which of the data samples correspond to significant loads and to compute stress at selected structural locations from data samples of the recorded parameters. Some methods determine the significant times by first finding peaks and troughs of the recorded parameters and then computing loads and stresses at these times. Other methods compute a time history of stress from the recorded parameter time histories and then find peaks and troughs of stress. Most methods use some combinations of these approaches.

This paragraph presents many of the detailed data processing and analysis steps by describing current systems for representative aircraft. The transport/bomber aircraft are presented in separate subparagraphs while the attack/fighter/trainer methods have been grouped.

6.2.3.1 C-141A L/ESS Methods

A system of data blocks is used to reduce the time history tapes of the C-141A L/ESS. There are two basic reasons the time history data is reduced to data block form. These are:

(a) Data blocking condenses the flight profiles to a compact form and common base so that data may be accumulated and combined for a number of flights.

(b) Data blocking reduces the data to a form consistent with the previously performed C-141 Individual Aircraft Service Life Monitoring Program (IASLMP) so that comparisons can be made between the C-141 L/ESS and C-141 IASLMP.

The C-141A L/ESS data blocks are defined
for both ground and flight operations and the primary parameters
defining these data blocks are fuel, cargo, speed, and altitude.
Fuel usage for the C-141A Life History Recording Program (LHRP),
the equivalent of the L/ESS, is computed from equations compiled
from the C-141A flight manuals. The equations were compiled for
normal flight operations including climb, cruise, and descent.
The C-141A LHRP computes flight fuel usage once per minute. The
altitudes at the beginning and end of each 60 second time period
are monitored. A basic cruise fuel is calculated and then this
is adjusted according to whether or not a climb or descent has
occurred.

The cargo data blocking is accomplished
by utilizing the dialed-in beginning airplane gross weight and
fuel weight in conjunction with the input empty gross weight.
The effective cargo weight is calculated as the beginning gross
weight less the beginning fuel weight and empty gross weight.

The speed and altitude data blocks for
the C-141A L/ESS are determined from differential and static
pressure measurements. The c.g. load factors, n_z and n_y, are
separated into gust and maneuver portions in the C-141 L/ESS
data reduction program. This separation is accomplished by
computing the frequency spectrum of the n_z or n_y time history by
performing a Fourier transform, applying a low pass digital filter
to the frequency spectrum, and then computing the inverse Fourier
transform to obtain a filtered time history. This separation
technique is based upon the supposition that the frequency content
of the load factor due to maneuver is sufficiently distinct from
the frequency content of the load factor due to gusts so that a
nominal "cutoff" frequency may be established on the frequency
spectrum. It is assumed that all of the power content of the spectrum
below this cutoff frequency is due to maneuvers and all of the
power content of the spectrum above this cutoff frequency is due
to gusts. The vertical load factor as it is digitized by the
recorder/multiplexer requires a discrete type Fourier transform.

The technique used to perform this discrete Fourier transform is the so-called "fast Fourier transform" (FFT).

This technique of gust and maneuver separation is shown in Figure 6-17. The total load factor time history, g (t), in Step A is transformed to the frequency domain via the fast Fourier transform (FFT) to obtain G(W) in Step B. The low pass filter function in Step C is multiplied by G(W) to obtain the maneuver spectrum of the load factor shown in step D, F(W). The inverse Fourier transform is than applied to F(W) to obtain the maneuver time history, Step E. The gust time history in Step G may then be computed by subtracting the maneuver portion from the total c.g. load factor.

After the load factor data is separated into its gust and maneuver components, it is peak counted by the data block in which the load factor occurs.

The strain data is peak counted in the form of a tabulation of the number of peaks falling within pre-determined band levels located about some instantaneous mean strain value. This data along with an average mean is computed for each flight and ground data block. The peak count routine therefore determines an instantaneous mean value for each data sample, sets band levels about this value, determines if a peak has occurred and identifies the band level in which the maximum value of the peak occurs.

The mean used for the strain peak counting is a running mean averaged over 6.4 seconds before and after the instantaneous value for which a mean is required. The mean averaging time of 12.8 seconds was selected in order to minimize the error in the peak count level of aperiodic peaks as well as in the mean level during step changes in strain level, e.g. during takeoff and landing.

The overall methods of damage calculations for the strain time histories in C-141 L/ESS are presented schematically in Figure 6-18. The S-N data and the quality levels are input to the Damage Chart Program which yields the graphical
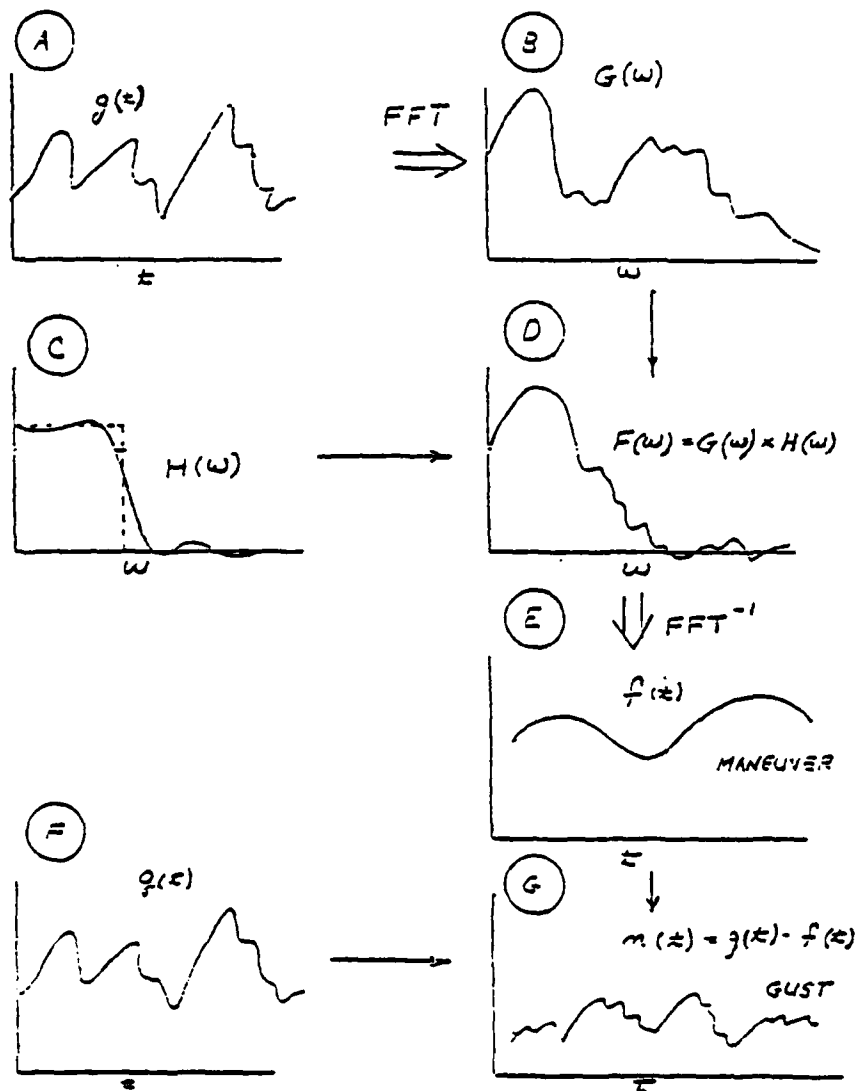
Figure 6-17. Schematic of Gust/Maneuver Separation
of C.G. Load Factor.
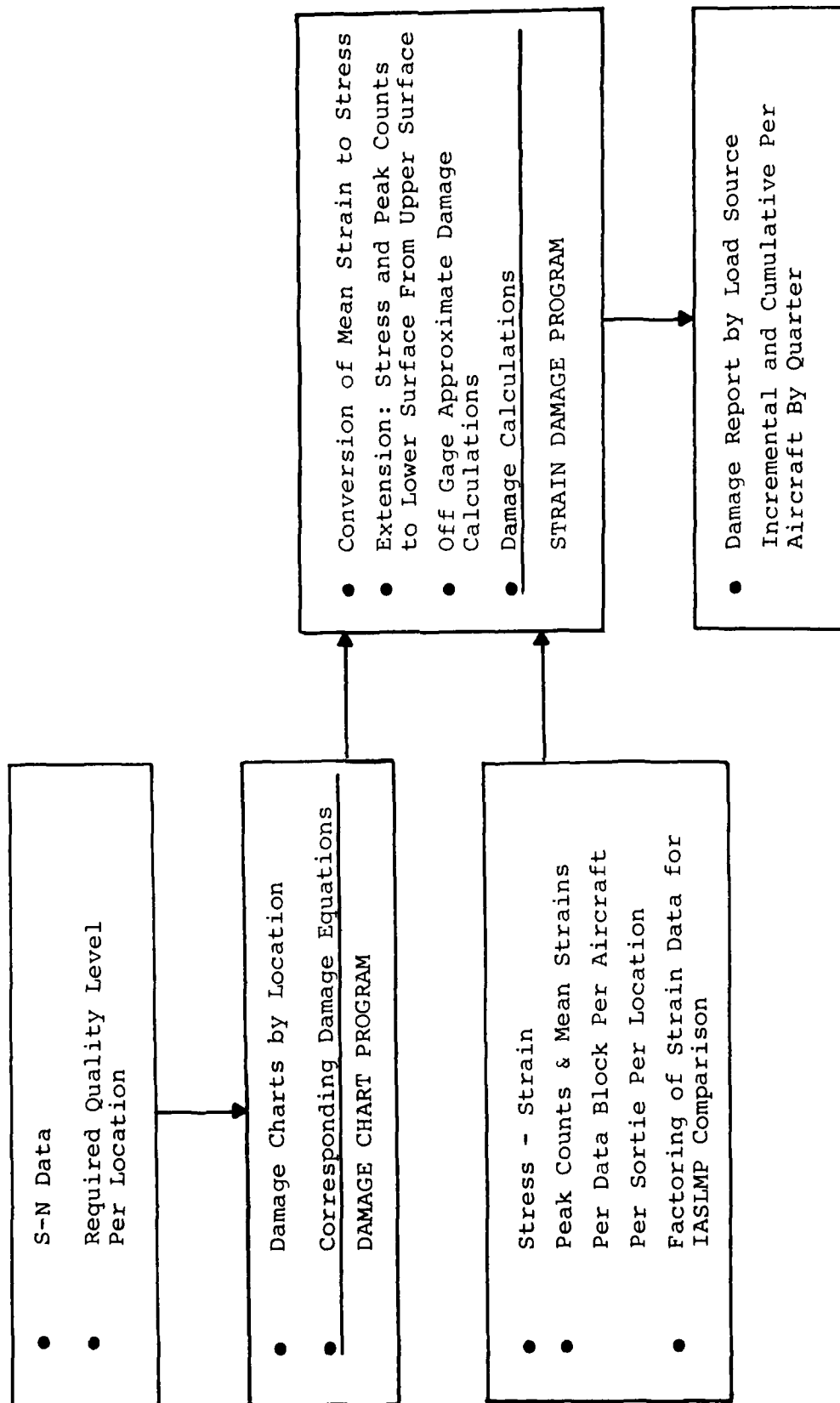
Figure 6-18. Life History Recorder Program Damage Calculations.

and analytical representation of S-N data by location. The analytical representations called Damage Charts are input to the C-141A L/ESS software. The strain-stress relations, peak counts, and mean strain per data block per aircraft per sortie per location and the characteristic data for factoring of strain data for IASLMP damage comparison are also the input data to the software.

6.2.3.2   F/FB-111 L/ESS Methods

The data reduction of the F/FB-111 L/ESS data is accomplished in two stages; these stages are called (1) Data Processing, and (2) Data Analysis, (Figure 6-19).

The Data Processing is divided into three phases. These phases are:

(a)   Quick Look Processing - Initial review to select flights with usable information.

(b)   Flight Identification - Retrieval of the Flight Usage Card Information (AFTO Form 71324).

(c)   Loads Edit Processing - Generation of compressed time histories of the recorder data.

The recorder data are reviewed on a flight-by-flight basis to determine the flights for which the data are usable for updating airframe and landing gear service load spectra. A digital computer procedure (referred to as Quick Look) has been developed to help accomplish this review. The Quick Look Procedure provides a digital listing of the maximum and minimum values for successive 33-second time intervals for each data item. The listing for an entire flight is reviewed for evidence of erroneous data. The following information is determined for individual flights for Loads Edit processing:

(a)   Null adjustments for data parameters.

(b)   Data parameters which are to be suppressed because of questionable for erroneous measurements.

(c)   Data time records for starting and stopping Loads Edit processing.

6-47

Figure 6-19. F/FB-111 L/ESS Data Flow.

DATA ANALYSIS

SLM REPORTS: •Current Damage •Remaining Life •Usage Statistics

SERVICE LIFE MONITORING COMPUTER PROGRAM

INITIAL: •Usage Model •Unit Damage •Past Usage

UPDATE: •Usage Model •Unit Damage Data

INDIVIDUAL A/P: •Usage •NZC Statistics

USAGE MODELS

UNIT DAMAGE DATA

ANALYZE MCR, NZC & USAGE CARD DATA

SERVICE LOADS SPECTRA

FATIGUE ANALYSIS

Sacramento ALC / Ogden ALC

DATA PROCESSING

TAPES: •Usage Data •NZC Data

CARD DATA REDUCTION

USAGE CARD & NZC CARD IDENTIFIERS MCR-A/P's

DATA REDUCTION: •Quick Look •Loads Edit

TAPES COMPRESSED MCR TIME HISTORIES

DATA COLLECTION TAC/SAC BASES

F/FB-111 Fleets

All F/FB-111 Airplanes

F/FB-111s with MCR

MCR MAGAZINES

USAGE CARDS & NZC CARDS

FIELD DATA TAPES (TIME HISTORIES)

SIGNAL DATA CONVERTER

MCR MAGAZINES RETURNED FOR REUSE

MCR - MULTIPLE CHANNEL RECORDER   NZC - CG VERTICAL LOAD FACTOR COUNTER

(d) Flight identification and description information (e.g., A/C SN, organization, data of flight, takeoff configuration, takeoff weight, mission purpose, flight profile, aerial refueling duration and weight, and landing weight).

The information needed for (1) selecting flights with usable data and (2) sorting of the usable data according to mission type and calendar period is provided by the Flight Usage Card and contains: date of flight, total airplane hours at end of flight; mission purpose; external store configuration; takeoff and landing weights; terrain following radar usage; aerial refueling usage information.

Definition of the above information requires identification of the flights for which data were recorded. The magazine labels provide identification of the recording airplane (serial number) and bomb wing and definition of the calendar period of the flights. A Quick Look listing of the data measurements is also available for each flight. This information is used in conjunction with a computer listing of Flight Usage Card information for individual flights to identify the flights with data -- the needed Flight Usage Card information is then read from the listing. This information and that generated during Quick Look processing are subsequently used through Load Edit processing to generate compressed time histories of the usable data.

The MCR Loads Edit Procedure (a digital computer program) is used to generate "compressed time histories" of MCR measurements for selected flights. These histories contain information necessary for updating airframe and landing gear service load spectra (load spectrum analysis) which are in turn used to update parametric damage rates for the F/FB-111 Service Life Management program. The comp essed time history for a given flight contains only a small percentage of the 240 multichannel recorder (MCR) measurements which are recorded per second of engine operation. During airborne operations, MCR measurements are preserved approximately once a minute during periods of inactivity. A period of activity starts when one or more of certain items

6-49

(referred to as Maneuver Activity Indicators, MAI) have values outside of predefined threshold intervals and ends when all have returned to values within these intervals.

During a maneuver activity period, "time hacks" of all data measurements are preserved for the following times:

(a) Time at start of maneuver activity period (approximately one-g trim data).

(b) Times when selected items (referred to as peak indicators, PI) have certain maximum values. For a given PI, this is the time of its maximum value between the time it exceeds its upper threshold and the next time it returns to its upper reset.

(c) Times when the PIs have certain minimum values. For a given PI, this is the time of its minimum value between the time it reduces to values less than its lower threshold and the next time it returns to its lower reset.

(d) Time at end of maneuver activity period (return to approximate one-g trim).

The compressed MCR time history for a given flight also includes time hacks of MCR measurement at selected times during ground operations. These times are selected by using the "peak-indicator" technique described in Items b and c above. In some case, the PI's for ground operations and flight operations are different. Identification of the PI's and MAI's for flight operations and the PI's for ground operations and definition of their associated threshold and reset levels are shown in Figure 6-20. Some of the PI's and MAI's are measured parameters while others are computed from the data measurements.

DATA ITEM	MANEUVER ACTIVITY INDICATOR (MAI) THRESHOLDS		PI No.	PI – THRESHOLDS AND RESETS			
	UPPER GT④	LOWER LT④		UPPER		LOWER	
				THRESHOLD GT④	RESET LE④	THRESHOLD LT④	RESET GE④
N_z	1.313 g	.75	1	1.5	1.125	.563	.938
N_Y	.125 g	-.125	2	.125	.063	-.125	-.063
DR	1.875 g	-1.875	3	2.813	.938	-2.813	-.938
DA①	2.344°	-2.344	4	3.906	1.563	-3.906	-1.563
DA②	2.344°	-2.344	4②①	7.813	1.563	-7.813	-1.563
V_{VT}③	NOT USED	NOT USED	5	3300 LBS	1650 LBS	-3300 LBS	-1650 LBS
V_{VTL}③	" "	" "	6	3000 LBS	1500 LBS	-3000 LBS	-1500 LBS
V_{HB}③	" "	" "	7	3000 LBS	1500 LBS	-3000 LBS	-1500 LBS
V_{HL}③	" "	" "	8	7500 LBS	3750 LBS	-7500 LBS	-3750 LBS
V_{HR}③	" "	" "	9	7500 LBS	3750 LBS	-7500 LBS	-3750 LBS
SPL	3.516°	N/A	10	6.328	3.516	N/A	N/A
SPR	3.516°	"	11	6.328	3.516	"	"
P	6.25 Deg/Sec	-6.25	12	31.25	6.25	-31.25	-6.25
q	1.563 Deg/Sec	-1.563	13	4.689	1.563	-4.689	-1.563
R	1.563 Deg/Sec	-1.563	14	4.688	1.563	-4.688	-1.563
$\dot{P}$	.194 Rad/Sec²	-.194	15	.818	.194	-.818	-.194
$\dot{Q}$	.048 Rad/Sec²	-.048	16	.136	.048	-.136	-.048
$\dot{R}$	.035 Rad/Sec²	-.035	17	.136	0	-.136	0

SEE NEXT PAGE FOR NOTES ①, ②, ③ AND ④.

NOTES:

① ~ To compute thresholds and resets for DA, the values shown in this table are to be added to DA trim which is computed every three records in Loads Edit...
where DA = HTL - HTR

② ~ Use these values to compute DA peak indicators for high-lift operations (Flap position > 5°).

③ ~ To compute peak indicator thresholds and resets for these load items, add the values shown in this table to trim values as computed by Loads Edit for PI-6) time hacks (MCR data at start of maneuver).

④ ~ GT = greater than, LT = less than, GE = GT or equal, LE = LT or equal to.

a)   For Flight Operations

Figure 6-20.   F/FB-111 MCR Maneuver Activity Indicators and Peak Indicators.

PI NO.	DATA ITEM	THRESHOLDS AND RESETS			
		UPPER		LOWER	
		THRESHOLD GT	RESET LE	THRESHOLD LT	RESET GE
1	N_z	1.313 ⑨	1.313	.75	.75
.2	N_Y	.125 ⑨	.063	-.125	-.063
3	N_x	.125 ⑨	.063	-.125	-.063
.4	DR	15.938 Deg	14.063	-15.938	-14.063
12	P	12.5 Deg/Sec	6.25	-12.5	-6.25
13	Q	3.125 Deg/Sec	1.563	-3.125	-1.563
14	R	3.125 Deg/Sec	1.563	-3.125	-1.563
15	$\dot{P}$	.273 Rad/Sec²	.194	-.273	-.194
16	$\dot{Q}$	.136 Rad/Sec²	.048	-.136	-.048
17	$\dot{R}$	.051 Rad/Sec²	0	-.051	0
5	NGP①	312.5 psi	-390.625	-312.5	390.625
6	MGPL①	312.5 psi	-390.625	-312.5	390.625
7	MGPR①	312.5 psi	-390.625	-312.5	390.625
8	F_{ins}	1000 LBS	500 LBS	-1000 LBS	-500 LBS

NOTES: GT = GREATER THAN, LT = LESS THAN, GE = GT OR EQUAL, LE = LT OR EQUAL TO
① ~ THESE PI THRESHOLDS AND RESETS ARE INCREMENTAL FROM THE PREVIOUS PEAK OR VALLEY

b) For Ground Operations

Figure 6-20. F/FB-111 MCR Maneuver Activity Indicators and Peak Indicators (Concluded).

The Load Edit Procedure classifies the
data preserved for the selected times into three categories:

Type 1 Data - Preflight Ground Operations

Type 2 Data - Flight Operations

Type 3 Data - Other Ground Operations
(ground operations during touch-and-go
landings, taxi-back landings, and ground
operations associated with the final landing
for a flight).

The resulting compressed time histories
of the data (Data Types 1, 2, and 3) for individual flights are
written on magnetic tape for subsequent analyses.

The compressed time history tapes and the
tapes containing the usage data and N_z counts are transmitted to
ASIMIS (Tinker AFB) for data analysis. The major data items that are
output from this data analysis are current damage, remaining life,
and usage statistics.

Equations of the general form shown below
were developed for computing maneuver loads for the "times" pre-
served in the compressed time histories.

$$\text{Load} = C_o + C_1 V_1 + C_2 V_2 + .. + C_n V_n$$

C's = Constant

V's = Variables in terms of MCR parameters

Selection of the variable terms and definition of the constants
is accomplished through application of linear multiple-variable
regression analysis techniques to concurrent measurements of
airplane loads and data parameters recorded during the F/FB-111
Category I Flight Test program.

The following steps highlight the main
facets of the maneuver loads data reduction of the FB-111 L/ESS:

(a) Maneuver loads are calculated according
to maneuver activity period by flight.

(b) Maneuver load peaks and valleys are
paired sequentially within a maneuver activity period to form load
cycles.

6-53

(c)   Each maneuver period is assigned a "Representative N_z" ($N_{z_{REP}}$).

(d)   All resulting maneuver load cycles are labeled as necessary to preserve identity of the USAF organization (wing), mission type, representative N_z, and mission segment, speed, wing sweep, and weight.

(e)   All maneuver load cycles with like loads and like labels (identifiers) are grouped and written on an output MCR load-cycle history tape.

(f)   Fatigue damage of individual maneuver load cycle groups are computed; identification labels are retained.

(g)   Fatigue damage with like identification labels are summed and preserved (with identifiers) on an output history tape.

(h)   Periodically, to update fatigue Unit Damage Data due to flight maneuvers, information on the MCR load-cycle history tape is grouped and scaled to define maneuver load spectra and fatigue damage according to mission type and organization, or mission type, organization, and $N_{z_{REP}}$, or mission segment and organization.

The following steps outline the data reduction methodology used for the recorder data ground-air-ground loads:

(a)   Ground-air-ground (GAG) load cycles are preserved on a flight-by-flight basis according to mission type and organization. The GAG load cycle for a particular flight consists of the maximum and minimum loads for the entire flight considering: (1) preflight ground static loads, (2) one-g trim flight loads, (3) flight maneuver loads, and (4) post flight ground static loads.

(b)   Fatigue damage due to GAG load cycles is computed and preserved according to mission type and organization on an output MCR load-cycle history tape.

(c) Periodically, to update SLM fatigue UDD, information on the MCR load-cycle history tape is grouped and scaled to define GAG load spectra and GAG fatigue damage according to mission type and organization.

Finally, the analyses of the L/ESS data pertaining to the landing gear loads and the Service Life Monitoring (SLM) Unit Damage Data (UDD) is accomplished as follows:

(a) Equations with MCR parameters as independent variables were developed for computing the following gear loads: Nose Gear-Vertical loads and side loads, Main Gear-Vertical, side, and drag for left and right sides.

(b) Time sequences of maximum and minimum loads are computed for individual takeoffs, touch-and-go landings, full-stop taxi-back operations, and final landings operations (SLM UDD operations) contained in MCR data sample.

(c) Each load time sequence is reduced to load cycles by applying the range-pair-range cyclic analysis technique supplemented in a manner to ensure definition of maximum-range load cycles for individual SLM UDD operations in the MCR data sample.

(d) Periodically, to update SLM UDD for landing gear, the MCR gear load cycles are grouped, scaled, and analyzed as necessary to determine load spectra and fatigue damage according to organization (base) and weight for 1,000 initial take-offs, 1,000 touch-and-go landings, 1,000 full-stop taxi-back opera-tions, and 1,000 final landings.

6.2.3.3   C-5A L/ESS Methods

The data reduction on the C-5A L/ESS is accomplished in two stages, the first at ASIMIS and the second at Lockheed-Georgia. The first stage is called "data processing and reduction" and the second "data analysis". This data flow is shown in Figure 6-21.
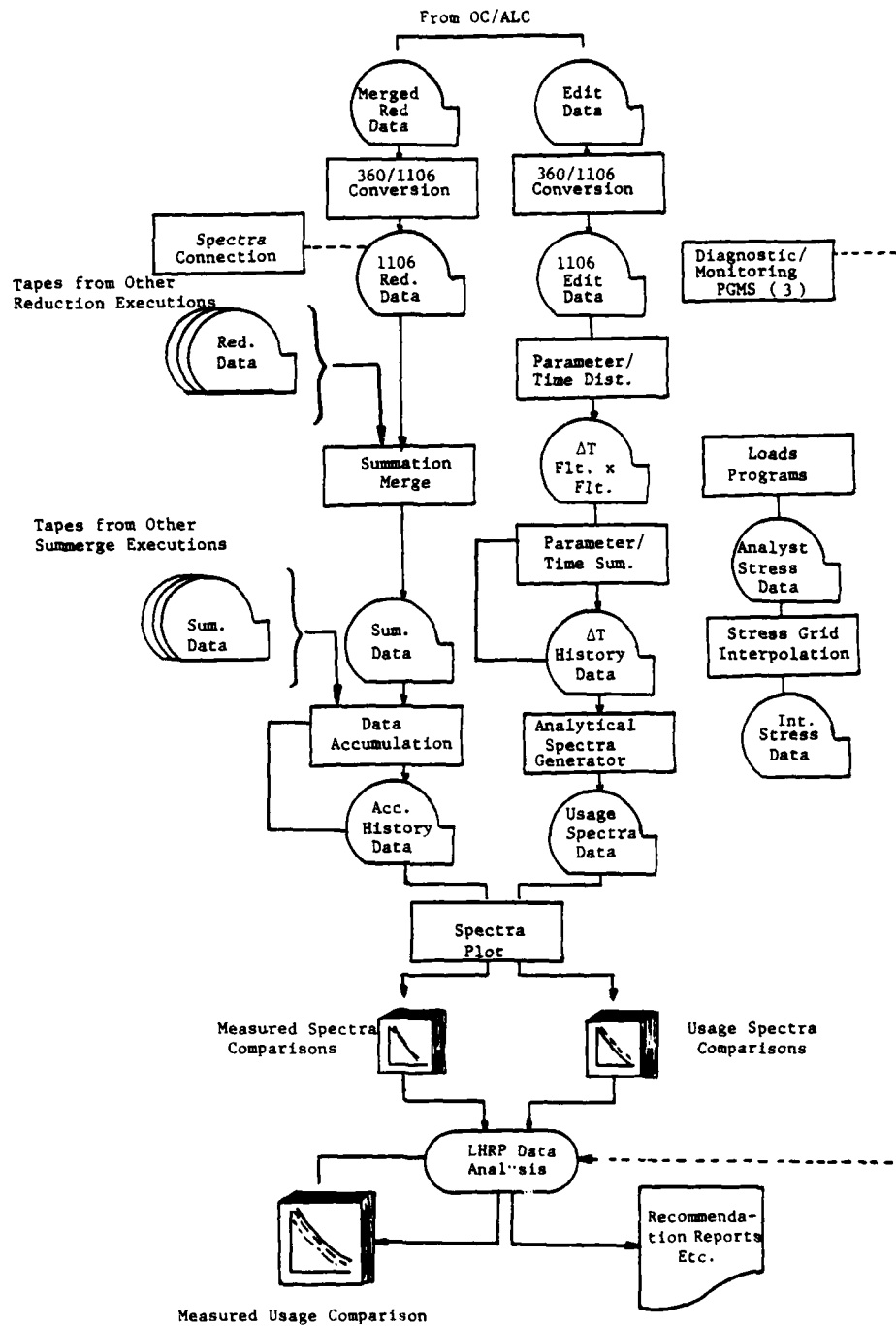
Figure 6.21. C-5A Network of Analysis Operations.

Data processing is the initial function in the C-5A L/ESS. It deals with the procurement and intermediate preparation of flight recorded data for L/ESS analyses and comparisons. The primary goal of Data Processing is to ensure that the data which ultimately reach the analysis stage are credible, error free and represent coherent flights. Data processing is composed of the individual operations defined in the following paragraphs.

The initial step in Data Processing is the extraction of L/ESS data from the Central Data Bank (CDB) at OC-ALC utilizing the L/ESS Data Extraction Program. The extraction program extracts onto magnetic tape all flight recorded L/ESS parameter data, MADAR trend messages, LRU messages and MADAR event messages which are used in L/ESS. The input to the program consists of all history tapes in the CDB which contain L/ESS aircraft data sets. The extraction program performs certain validity checks on the data to determine that Mach number, CG load factor, and pressure altitude exist and are basically credible; and determines that the data depict a true flight, that is, that there is a takeoff followed by a landing, etc. A printout of documentary parameter time histories and reduced (periodic time weighted average) time histories of time varying parameters is provided for each flight. The final step in the data extraction process is the merging of extracted tapes from several executions to produce packed tapes prior to Data Processing.

Data Correlation is the manual process whereby MAC Form 89 data required in the L/ESS are identified. The source of this information is the printout from the Individual Aircraft Service Loads Monitoring Program (IASLMP) Combined Usage Program. The salient features of an extracted flight are determined by manual inspection of the Extraction Program time history printout. This information, along with aircraft serial number, airframe hours and flight data from the MADAR header, (also from Extraction printout) are compared with similar information for Combined Usage flights flown in the same approximate time span. When the information for an extracted flight and a

6-57

MAC 89 flight agree suitably well, the pertinent information are tabulated and card input for the Edit Program is formed.

The extracted data, which are compressed digital time hisories of L/ESS flight recorded parameters (and other data) are operated upon by the L/ESS Edit/Correlation Program. This program performs detailed edits on each parameter and removes erroneous or bad data on a point by point basis, or, if severity criteria are exceeded, rejects entire data channels. Entire flights are rejected if a key parameter (Mach number, pressure altitude, C.G. load factor, flap position, ground speed, or aileron position) is failed. A flight profile is constructed for each flight by collectively interpreting the recorded data. The flight profile provides a "road map" of each flight for the programs which process the data further. It consists of a list of aircraft activity indicators (takeoff, taxi, cruise, climb, descent, etc.) and a start time for each. The profile itself is edited following compilation to ensure overall flight coherency. MAC Form 89 data are card input to the Edit Program and are combined with the flight recorded data for each flight. This information consists of aircraft and flight identification information, event codes (aerial refueling, contour flying, etc.), cargo weight and the fuel weight history. The MAC Form 89 data are obtained from IASLMP Combined Usage printout as explained previously.

A manual review of the Edit Program output is performed at the completion of each Edit execution. The purpose of this review is to isolate erroneous data or flights which may have eluded the checks and edits built into the Edit Program because of peculiar circumstances in the recorded data. The manual review of edit results proved to be an effective procedure in the SLRP and does not imply that the Edit Program is deficient in checking logic or is otherwise inadequate. A completely automatic editing program would be prohibitively large, considering the number of parameters involved and the possible number of combinations of erroneous data in various combinations of channels. Another unacceptable alternative is a simpler program which fails all flights which contain erroneous or even questionable data. This approach would result in a very small sample of data to analyze.

The results of the manual review and edit
are introduced into the machine edited data tapes using the Edit
Utility Program. This program allows for changes to be made to
the flight profile, header information and the lists of failed or
inoperative parameters. Entire flights can also be deleted from
the output by using the Edit Utility Program.

The purpose of the Data Reduction phase
of L/ESS is to convert the edited data produced within the Data
Processing phase to other forms which are more suitable for the
analyses and comparisons performed within the Analysis phase.
The Data Reduction phase is comprised of the conversion of edited
time history data to histogram and event occurrence forms, the
review of resulting reduced data for consistency, and the organiza-
tion of reduced data for subsequent Analysis phase operations. All
operations within the Data Reduction phase are performed on a
flight-by-flight basis.

The edited time history data of specific
parameters are peak counted about calculated mean levels. Histo-
grams are produced from the peak counted data for each applicable
parameter for appropriate flight profile segments. The resulting
data identify the number of peaks occurring in predetermined
magnitude bands during individual flight profile segments. Maximum
values of CG vertical load factor (NZCG) and wing stresses are
calculated during landing impact, Ground-Air-Ground (GAG) and
Air-Ground-Air (AGA) cycles. Additionally, the occurrences of
specific events such as In-Flight Thrust Reversal, Engine Run-up,
etc. are counted and each flight is classified according to the
IASLMP 64 Representative Missions definition.

The primary purpose of reduction is the peak
counting of NZCG, wing stresses, and right aileron angle. A peak
is defined as the maximum excursion of a time history trace between
successive crossings of a mean (reference) level. Therefore, the
peak counting method employed requires a determination of mean level
for each of the peak counted parameters. The mean level for NZCG
is established at a constant value of 1.0g, however, the mean level

6-59

for right aileron angle and each of the wing stresses are calculated independently by a variable mean determination method. The determined variable mean for these parameters depends upon the local amplitudes and activity level of the specific parameter recordings and, therefore, varies from peak to peak.

The resulting peak occurrences are banded by specific magnitude ranges and retained by individual occurrence of flight profile segments. NZCG is peak counted for all segments, right aileron angle is peak counted for all in-flight segments, and wing stresses are peak counted for all segments except landing impact. The amount of elapsed time (Δ time) is maintained for each individual segment along with the corresponding banded peak occurrences.

Incremental stress excursions due to impact events are calculated for each operative stress channel for each landing impact. In addition, rate of sink is calculated for each impact event as a function of fuel weight, cargo weight, and impact NZCG. The impact NZCG value is determined within the Data Processing phase for each landing impact segment and is included in the edited time history data.

Calculations are performed to determine peak-to-peak extreme values of NZCG and wing stresses during each GAG cycle and each AGA cycle. A GAG cycle begins at the start of a flight and terminates at the end of flight. If a flight contains multiple full-stop landings, the number of GAG cycles will equal the number of full-stop landings. An AGA cycle will exist for each touch-and-go landing which is directly preceded by traffic segment. The AGA cycle begins at the start of prelanding traffic and terminates at the end of post-liftoff traffic.

The cumulative number of specific events is determined by flight. The events that are identified and accumulated are: In-flight thrust, Ground thrust reversal, Flaps movements, Aerial refueling, Contour flying, Airdrop, Touch-and-Go landings, Full-stop landings, Engine run-up, and Take-off abort.

The purpose of the identification of these events is to provide the Analysis phase a condensed history of particular aircraft activity that is not readily available in the normal reduced data. A flow diagram of the data reduction operation is shown in Figure 6-22.

The resulting reduced data of each flight are manually reviewed to ensure the completeness and consistency of the data. The data are scanned for obvious errors, mission flights or items and inconsistent trends. Suspect data items or inconsistencies are noted for special scrutiny within the Analysis phase.

The reviewed reduction data are organized for subsequent Analysis operations by the execution of several utility operations. Flights determined by manual review to be totally unsatisfactory for Analysis are deleted. Individual sets of reduced data are sorted and merged. Audits of the resulting merged flight-by-flight data are produced for use within the Analysis phase.

The reduction operations are performed through use of the L/ESS Data Reduction Program and the reduced data utility operations are performed through use of the L/ESS Data Reduction Utility Program. All reduced data are produced on paper printout and magnetic tape. The paper printout is utilized in manual flight-by-flight review. The reduced data are transmitted to the Analysis phase, after utility operations, on magnetic tapes accompanied by corresponding data audits.
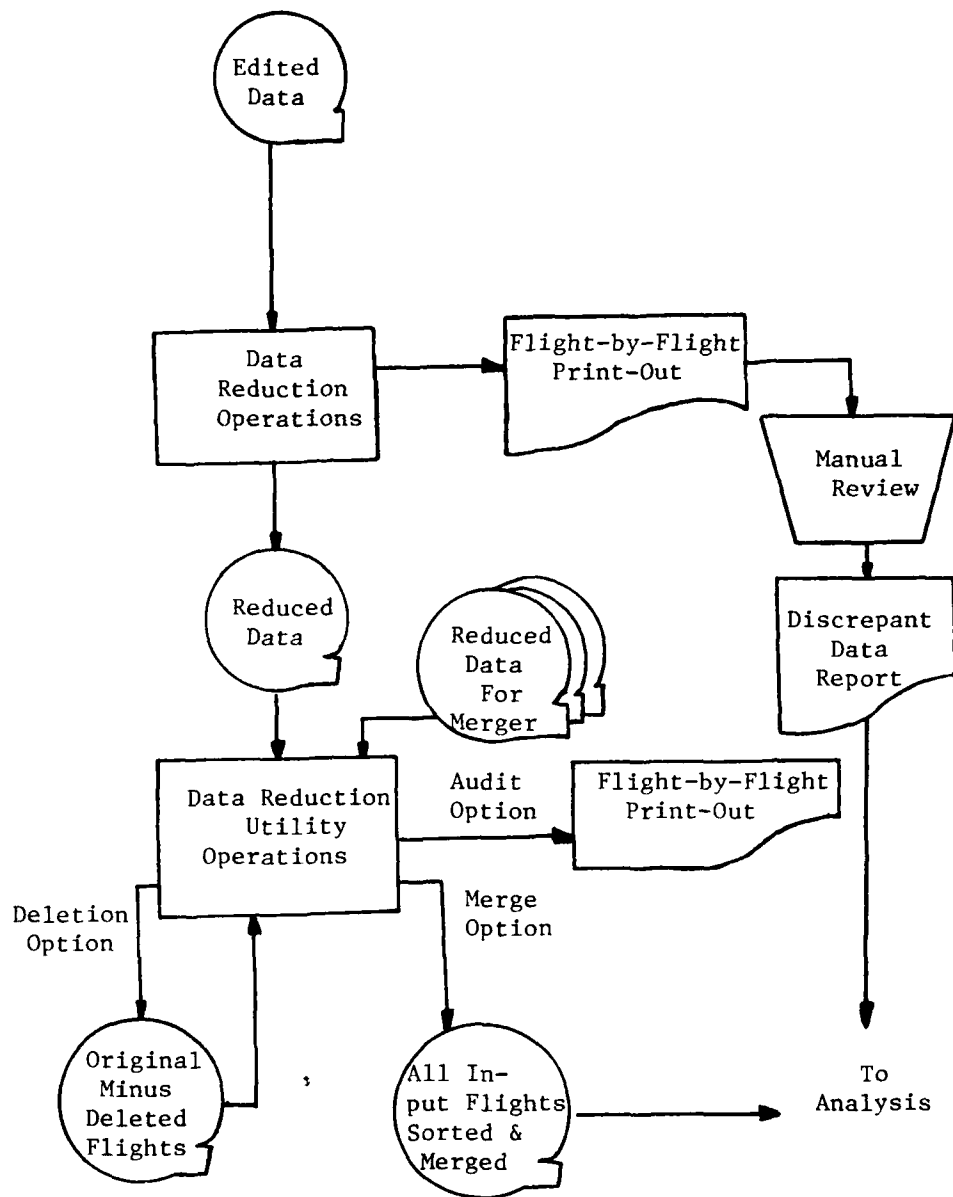
Figure 6.22.   C-5A L/ESS Reduction Phase Data Flow.

6-62

Data analysis is the final step in the C-5A L/ESS sequence. It is accomplished at Lockheed-Georgia. The primary goal of data analyses in the L/ESS is to compare information based on measured spectra, i.e., right aileron deflection, load factor and wing stress spectra, for a current time span with previously established information and determine if the loading experience of the aircraft is changing. This procedure will be repeated continually throughout the life of the C-5A fleet.

A secondary analysis consists of the development of spectra based on analytical stresses and usage data derived from measured documentary parameters. Comparisons of the measured stress spectra with the analytical/usage spectra further indicate whether changes in spectra (from one time span to another) are due to operating environment changes or changes in the manner in which the aircraft are being used. The results of these comparisons will be documented periodically in reports and status letters.

The generation of measured spectra is accomplished by cumulation of flight-by-flight reduced data produced within the Data Reduction phase of L/ESS. Analytical wing stress data are generated by the cumulation of usage information derived from flight-by-flight edited data produced within the L/ESS Data Processing phase.

The generation of measured and analytical spectra are accomplished through a highly computerized network of analyses in which flight-by-flight data are cumulated by category, normalized by time, and produced in plotted or tabular form for comparisons.

6.2.3.4   T-43A L/ESS Methods

The T-43A L/ESS uses the MXU-553A recording system. Documentary data values are dialed into the recorder at the start of each flight. These data are aircraft serial number, initial gross weight, initial fuel weight, base, mission type, aircraft hours, and data. Parameters whose values are recorded as

variables during the flight are altitude, speed, fuel weight, air-ground indication (from R.H. main landing gear squat switch), time, and three channels of c.g. load factor data. These three channels are lateral acceleration (Δn_y), vertical acceleration (Δn_z) for frequencies from 0 to 0.2 cps, and vertical acceleration for all frequencies within the recorder system capabilities (0 to 6 cps.). The recorder is activated by release of the parking brake.

The counting accelerometer records numbers of exceedances for six c.g. vertical load factor levels and also records elapsed time. (The counting accelerometer is connected to the squat switch on the R. H. main landing gear, and records only during the time when the gear oleo is extended). The load factor levels for which counts are made are 0.4, 0.7, 1.3, 1.5, 1.7, and 1.9 g's. Only the count for each level exceeded is made prior to crossing a reset value of either 0.9 or 1.1 g's.

The recorder data are reformatted, transcribed and compressed at the ASIMIS facility at Oklahoma City ALC. Compression is accomplished using the Data Compression Computer Program. Three means of compressing the recorder data are utilized. These are:

(a) Elimination of most data points having values smaller than prescribed threshold values. The threshold values are ±0.05g for Δn_y, ±0.2g for Δn_z for flight, and ±0.1g for Δn_z for ground loads.

(b) Elimination of intermediate points between a peak (valley) and the next valley (peak).

(c) Elimination of pairs of successive peaks and valleys whose magnitudes differ by less than 0.03g for Δn_y and 0.1g for Δn_z.

The compressed recorder data are reduced using the Data Reduction and Analysis Program. The more important features of this program are:

6-64

(a) The retained peaks and valleys, for each of the three load factor channels, are grouped in blocks of speed, altitude, gross weight and air or ground operational regime. Within each block, the mean values of speed, altitude and gross weight are calculated for all data entered into the block.

(b) Within each data block, and for each of the three load factor parameters, the data are reduced by the level crossings method. This method produces one exceedance count of a given value of Δn each time that Δn level is crossed, with a positive slope, by the compressed Δn time-sequence.

(c) Within each flight condition data block, the number of counts at each Δn_z level for the 0 to 0.2 cps channel (maneuver) is subtracted from the corresponding number of counts for the 0 to 6 cps (gust plus maneuver) channel. The remainder is the number of counts for gusts. It is possible, although rare, that this technique can result in a negative number of counts. This could occur for a data block where the amount of flight time is quite small, and/or where the loading activity is very low. It results from a peak on the maneuver channel not being the same as a peak on the gust plus maneuver channel, and from the maneuver peak being displaced enough in time from the nearby gust plus maneuver peak so as to be in a different data block. In this case, there would be no gust plus maneuver count from which to subtract the maneuver count, so a value of minus one would be output for the gust count. If this happens, the minus one should be disregarded, and treated as if it were zero. Another possibility which can result from subtracting maneuver counts from counts of gust plus maneuver, for small data samples involving multiple data blocks, is to have more counts for a higher load factor level than for a lower level. This could possibly show up in the tabulated data, but should disappear when more data are obtained.

(d) For ground loadings, the values for
the highest peak and lowest valley of the 0 to 6 cps Δn_z channel,
during the first three seconds from touchdown, are used for level
crossing counts for landing impact. If only one point occurs in
the three second period, counts are made from one g to the peak or
valley. All of the Δn_z ground data are used for level crossing
counts. The landing impact counts are subtracted from the total
counts to produce Δn_z data for taxi. All Δn_y data for ground
conditions are considered as taxi. The 0 to 0.2 cps Δn_z channel
data are not used for ground conditions.

(e) Selected data blocks are checked for
data convergence. Each time new data are reduced, exceedance values
in a data block for selected Δn levels (normalized to per 1,000 hours,
per 1,000 miles or per 1,000 flights) are calculated for all data
to date. These values are compared with the comparable values from
previous data reductions. These comparisons are plotted in ratio
form and are monitored to determine when the data have converged.

(f) The results of the computer program
operations are displayed in various tabular and/or graphical formats.
These are used for data evaluation.

The counting accelerometers are read at
approximately five week intervals. The values for each of the
load factor levels and for the elapsed time indicator are recorded
on the T-43A counting accelerometer forms along with the airplane
tail number and the data. The data from the forms are recorded
on the T-43A counting accelerometer forms along with the airplane
tail number and the data. The data from the forms are reduced to
exceedances per 1,000 flight hours for each load factor level and
for each airplane. All incremental load factor counts and elapsed
time values are from the first counting accelerometer report after
the airplane was delivered to the Air Force. Invalid, or suspect,
data due to malfunctions in the counting accelerometer system are
not used. The counting accelerometer data are then reduced by the
Data Reduction and Analysis Program and the output results are
used for data evaluation.

6.2.3.5   C/KC-135 L/ESS Methods

In general, all calibrated channels for the C/KC-135 L/ESS are handled in much the same manner, with only the treatment of intercepts differing. Basically, a conversion is first made to voltage from digital levels. This is performed by making a least squares linear fit through the three points determined by the three calibration levels on each channel.

After calibration checks the first step in the strain mean computation is the application of numerical filters to remove the relatively high frequency components from the strain data. Low pass filters of the type developed by Martin and Graham were chosen.

The use of the digital filtering techniques remove frequencies above 0.04 cycles per second from the data. However, it is desired to remove even lower frequency data in some instances. Specifically, it is not thought to be desirable to allow the mean strain to respond to maneuvers lasting up to 10 minutes. This type of mean shift is faired-through by applying a series of 100-second windows to the digital filter mean strains. In essence, the mean strain is examined at intervals of 100 seconds and if the voltage difference exceeds 0.2 volts (1,250 psi) at each of the six 100-seconds times after the time of interest, it is allowed to follow the shift. If at any of the 100-second windows the values do not exceed the 0.2 volt value, the mean is faired-through the short duration shift.

The positive and negative peaks on the acceleration and strains are basically defined in the same manner. A primary peak count is made in all cases. However, for two different reasons, the method of computing these primary peaks is different for the accelerations from that used for the strains. A primary peak in the C/KC-135 L/ESS is defined as the maximum excursion of the variable between crossings of the mean level of the variable. The difference between the analysis of the strains

6-67

and of the acceleration is the determination of the mean. The value of the mean acceleration which is strived for is the 1.0g level. The mean strain is not allowed to change for manuevers but is permitted to change during take-off and landing.

Since the mean value (1.0g) of acceleration is assumed to never change, it is possible to compute a running position of the 1.0g level in terms of digital counts and to subtract this mean level from all peaks detected to obtain the primary acceleration peaks. Primary acceleration peaks are detected by an algorithm which analyzes the samples of acceleration one by one and saves the sample if it is greater or less than the previous sample, depending upon whether the values are increasing or decreasing, respectively. This procedure is started when the data crosses the 1.0g mean, and is terminated with the return of the data to the 1.0g mean. The peak value and the time it occurred are written on a disk, if the peak value exceeded threshold.

The strain mean, however, changes during a flight because of changes in air loading, weight, and autopilot and flap positions. Because of these changes, which are sometimes rather rapid, the running value of the mean cannot be computed. The mean values, as computed by the digital filtering techniques, do not become available until sometime after the strain data is analyzed for peaks. For this reason, all peaks (primary and secondary) on strain are retained until such time as they may be compared with the mean. When this is done the secondary peaks are discarded.

The algorithm for peak determination on the strains analyzes the data point by point, and each time there is a change in direction the sample is saved as a possible peak/valley if the change from the last such peak/valley candidate (change in direction) is greater than threshold. At such time as a new peak/valley candidate is found, the previous peak/valley candidate is established as an actual peak/valley and is output, along with its time of occurrence, to disk.

6-68

The output from the C/KC-135 L/ESS consists
of ordered panel records followed by strain records and acceleration
records, each containing all strain and acceleration peaks occurring
after the panel time and before the panel time. A second program,
VGH, which reads the EDIT output tape, outputs a printed tab and
a magnetic tape, both of which contain a time history of the flight
and statistical distributions of load factor and stress data.

6.2.3.6 Attack/Fighter/Trainer L/ESS Methods

For aircraft with strain measurements, the
stress spectra is calculated at the instrumented critical location
by transforming from strain to stress and sequentially pairing
stress peaks and valleys to form stress cycles. For all other
critical locations as well as aircraft types with no stress
measurements, the calculation of stress at each location is derived
from L/ESS measured aircraft motion parameters, control deflections,
weight and configuration. This calculation may be accomplished
by a linear combination of recorded parameters where the coefficients
are determined from analytical stress derivations or regression
analyses of flight test data. Another approach to the calculation
is to compute component interval loads through the use of unit
loads and then calculate the stress at the critical location.
Again, the stress peaks and valleys are paired to form stress cycles.

The total number of stress occurrences for
each stress level for each flight is obtained by summing over the
entire range of all airspeed, altitude, and load factor occurrences.
These form the stress exceedance spectra for each critical point
and each mission type which can be compared to those assumed for
design. Any differences call for the update of the spectra which
now becomes the baseline operational spectra.

6.3   L/ESS IMPLEMENTATION

The L/ESS planning starts with the airframe contractor's proposal when he proposes the percentage of the fleet to be equipped with L/ESS instrumentation and the structural parameters to be monitored and recorded. The Air Force will review the proposed program and will include firm requirements in the airplane contract specifications. The contractor will also propose a method to detect changes in aircraft usage.

After contract award, the contractor will select specific equipment for the L/ESS instrumentation, will install the purchased and/or government-furnished equipment in the selected airplanes, will develop analysis methods and data processing software, and will process the recorded data for three years after delivery of the first production airplane. At the end of the three-year period, the contractor will provide for transfer of all data processing functions to the Air Force.

The output of the L/ESS will be a baseline operational spectra in a form suitable for input into the durability and damage tolerance analyses update.

6.3.1   L/ESS Planning

The objective of the loads/environment spectra survey (L/ESS) is to obtain time history data of all those parameters necessary to define the actual stress spectra for critical areas in the airframe. The L/ESS is performed on a fleet immediately after the initial design phase because past experience has shown that the actual usage and stress spectra on the airframe may differ quite significantly from those assumed during design. It is necessary therefore to assess the effect of these differences on the durability and damage tolerance analyses (DADTA).

When the contractor selects the parameters to be monitored by the L/ESS recording systems he, in the process, is making a significant decision about his ultimate recorded data sample size. Through a prudent choice of parameters and types of sensors, the structures engineer can improve recording system reliability by a factor of two or more. The approach is a much

6-70

more efficient method of increasing sample size than merely doubling the number of instrumented aircraft.

No matter which parameters are selected, there will be a significant proportion of the recorded data during which one or more of the instrumentation channels is malfunctioning so that the recorded data is invalid. In terms of the number of monitored flights, the expected percentage with invalid data has varied between 40 percent and 100 percent based on past experience with L/ESS recording programs.

To improve the data sample size, the structural analyst should: 1) select parameters with proven sensor circuit reliability, 2) improve the reliability of the parameter circuits by redundant instrumentation (multiple strain gages clustered at the same location, etc.) and 3) specify special installation techniques or sensor types which have a record of better results. The importance of this aspect of L/ESS planning cannot be over-emphasized.

The percentage of the fleet or the number of instrumented aircraft is not as important as the deployment of the instrumented aircraft so they sample a representative cross section of fleet operation. The planned fleet operation and deployment should be considered when the number of instrumented aircraft is determined. The number of instrumented aircraft should be directly proportional to the number of operational bases and the number of mission profiles which will be included in the fleet operation.

6.3.2 L/ESS Analysis Methods and Software Development

The purpose of the L/ESS data is to verify or update the usage spectra of the design, damage tolerance, and durability analyses. A secondary use of the L/ESS data is to provide information to update structural design criteria for future aircraft. The contractor must develop methods to analyze the recorded data and the software to process the raw data into a useful form. The selection of the analysis method is made at the time the L/ESS

parameters are selected. Although variations in the method may be made later, the choice of parameters precludes any major change in the analysis method.

The L/ESS analysis must convert the recorded parameters into a suitable form for the durability and damage tolerance analyses update. The required analysis data is generally a sequence of stress cycles at critical structural locations determined by analysis or test. This stress sequence is used to calculate crack growth at the critical locations and to estimate the airframe economic life by adjusting the results of the durability test to account for the actual usage. With this objective in mind, the contractor must devise a system of L/ESS data flow.

Two types of L/ESS analyses are popular in current programs. In one type, the L/ESS parameters are aircraft motion measurements and control deflections. This data is input into a stress model to compute stresses at the required critical locations. In the other type of analysis, the L/ESS parameters are strains at selected points in the structure. These strains are transferred to stresses at the required critical locations.

There are arguments to support both of the above methods of L/ESS analysis. The instrumentation for the motion parameters is simpler and more reliable. The use of the loads and stress models is more complex and is less accurate than strain measurements at the critical locations. On the other hand, the strain systems are more difficult to install and calibrate and cannot usually be installed at the critical locations because of the accessibility of these locations. Finally, the motion parameters are more suited to use in design criteria for future aircraft.

This selection of the basic method for analysis and the attendant choice of recorded parameters is the most difficult choice in the L/ESS program. Once that choice is made, the remaining development is relatively straightforward.

The first step in the software development is the definition of overall data flow and the various data handling steps. The major difference in the various L/ESS data systems is in the sequence of steps and the number of points where manual intervention is required to proceed with the processing. At each point where manual intervention is required, a data tape is used as temporary (or permanent) storage of the processed data.

Over the past several years, the airframe contractors have developed a new L/ESS software system for each current aircraft system. Guidance has been provided by ASD with regard to how the system should be designed. Consequently, there is some degree of standardization of procedures and data products among the systems. However, differences in aircraft result in significant differences in L/ESS programs and data products.

A data product should be obtained for use in design criteria. Typical design criteria presentations are: bivariate tables of load factor peaks versus airspeed, altitude, or weight; peaks per thousand hours above various load factor levels by mission type or mission segment; multi-variate tables of combination and rate variables; and the frequency and magnitude of events such as landing impacts, gust encounters, and weapon deliverables. Convenient tape formats for storage of the L/ESS data would be: 1) edited and compressed input data, 2) peaks of each critical parameter and coincident values of all other recorded parameters, and 3) sequenced peaks and troughs of stresses at all critical structural locations. If the L/ESS software permitted re-entry of these tapes as input into the subsequent software routines, then the tapes would provide economical storage for the input data in the partially preprocessed forms.

SECTION 7

REFERENCES

SECTION 7

REFERENCES

1. Clay, L. E., et al., "Force Management Methods Task I Report - Current Methods," AFFDL-TR-78-183, December 1978.

2. Berens, A. P., et al., "Force Management Methods Task II Volume I, Summary and Analysis Considerations," AFWAL-TR-80-3120, Volume I, November 1980.

3. Morcock, D. S., Brown, K. E., Davis, J. C., and Johnson, R. L., "Force Management Methods Task II - Volume II - Transport/Bomber Aircraft - Evaluation of Potential Improved Methods," AFWAL-TR-80-3120, Volume II, November 1980.

4. Larson, C. E., and White, D. J, "Force Management Methods Task II - Volume III - Attack/Fighter/Trainer Aircraft Evaluation of Potential Improved Methods," AFWAL-TR-80-3120, Volume III, November 1980.

5. Bachman, R. W., and H. M. Wells, Jr., "Detail Requirements and Status Air Force Structural Integrity Program, Part I Background and Requirements," ASD Technical Note 61-141, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, September 1961.

6. "Air Force Aircraft Structural Integrity Programs: Airplane Requirements," ASD-TR-66-57, Aeronautical Systems Division, Wright-Patterson Air Force Base, 1968.

7. Military Standard, "Aircraft Structural Integrity Program, Airplane Requirements," MIL-STD-1530 (USAF), 1 September 1972.

8. Manning, S. D., et al., "Durability Methods Development - Volume I - Phase I Summary," AFFDL-TR-79-3118, Volume I, September 1979.

9. Wood, Howard A., and Robert M. Engle, Jr., "USAF Damage Tolerant Design Handbook: Guidelines for the Analysis and Design of Damage Tolerant Aircraft," AFFDL-TR-79-3021, March 1979.

10. Saff, C. R., "F-4 Service Life Tracking Program (Crack Growth Gages)," AFFDL-TR-79-3148, December 1979.

APPENDIX A

AF REGULATION 80-13 and MIL-STD-1530A

Research and Development

AIRCRAFT STRUCTURAL INTEGRITY PROGRAM

AFR 80-13, 16 Jul 76, is supplemented as follows:

1a. HQ USAF specifies the required service life in the system program management directive. The AFSC program manager will develop the aircraft to meet the required service life for the specified mission spectrum.

1b. The AFSC program manager will determine the service life capability for aircraft systems in acquisition (pre-PMRT). The AFLC ASIP manager will determine the service life capability for aircraft systems in operation (post-PMRT).

2. The AFSC program manager, the AFLC system manager, and the user are responsible for the optimum execution of the ASIP.

4a. MIL-STD-1530 does not include provisions for rotating parts of helicopters. The Deputy for Engineering (EN) ASD will assist each AFSC program manager in preparing a structural integrity program consistent with the concept of MIL-STD-1530.

6a(1) The program manager will forward eight copies of the initial coordinated ASIP master plan to the HQ AFSC systems officer (SYSTO) 30 days before full-scale development begins. The master plan will be revised or revalidated annually, and the revisions or statement of revalidation will be forwarded to HQ AFSC in eight copies for forwarding to HQ USAF. The program manager will provide AFLC and using commands copies of the approved master plan, revisions, and notices of revalidations. See attachment 1 for master plan format and content.

6a(2) For programs that do not follow this phase sequence, the program manager will include appropriate ASIP requirements in the program documentation at the earliest time to be in a position to have a fully coordinated cost effective ASIP before full-scale development begins.

6b. For a joint service program, the designated AFSC deputy project officer is the AF ASIP manager until PMRT.

6d. For AFLC managed programs, the ASIP manager, in conjunction with the system manager, will revise the ASIP master plan, coordinate with the participating agencies, and submit the plan to HQ AFLC/LOE for coordination and forwarding to HQ USAF for approval.

6e(Added). For systems covered by a and b above, AFALD/PT and the ALC (MMA or MMS) will mutually resolve and then designate an AFLC ASIP focal point for each aircraft system for which AFSC has program management responsibility. As a minimum, AFLC/LOE and the AFSC program office will be informed of the initial focal point designation. The designated focal point is responsible for obtaining master plan coordination from all involved AFLC organizations and coordination of the final version with HQ AFLC/LOE, providing ASIP interface and continuity with the AFSC program office and involved AFLC organizations, and ensuring that lessons learned from operational aircraft service experience are considered in the ASIP for aircraft being acquired by the Air Force.

7a. The PM will submit eight copies of the fully coordinated ASIP master plan to the HQ AFSC SYSTO for forwarding to HQ USAF. When coordination cannot be obtained, submit the issues and rationale for the ASD position with the proposed revisions. ASD/ENFS coordination is mandatory for all ASIP master plans drafted or coordinated in AFSC. ASD/ENFS will ensure all master plans conform to the required format and content. For AFLC managed aircraft, the ASIP manager will submit the coordinated ASIP master plan to HQ AFLC/LOE for coordination and forwarding to HQ USAF for approval.

7b. AFALD and ALC/MMSR will review and obtain appropriate coordination on proposed revisions to MIL-STD-1530 and submit recommendations to HQ AFLC, as required. ASD will forward to AFSC/SDD the fully coordinated proposed revisions to MIL-STD-1530.

8. The AFSC SYSTO will forward six copies of the coordinated HQ AFSC approved master plan to HQ USAF/RDP for approval and distribution to appropriate HQ USAF directorates and one copy to AFSC/SDD for retention. For AFLC managed aircraft, the ASIP manager will submit eight copies (nine for aircraft in Security Assistance programs) of the coordinated master plan to HQ AFLC/LOE. Two copies of each master plan will be retained at HQ AFLC and the remainder forwarded to HQ USAF for approval and distribution to the appropriate directorates. Also, the ASIP manager will provide copies of the approved master plan to the ASIP OPR of each command using the aircraft, AFALD, each ALC/MMSR, OC-ALC/AI, and ASD/ENFS.

10b. The AFSC organizations responsible for acquisition of aircraft systems or operation of aircraft will develop policies and procedures to implement this supplement. HQ AFSC (SD) will implement the requirements for systems in acquisition. HQ AFSC (LG) will implement the requirements as they pertain to AFSC-owned or -operated aircraft including bailed aircraft.

12. HQ AFSC (SD) is the command OPR for the ASIP for system acquisition. HQ AFSC (LG) is the command OPR for the ASIP for AFSC-owned aircraft.

12a. The designated program manager for each aircraft system being acquired or used by the Air Force is the ASIP manager until PMR is transferred to AFLC.

12b. The program manager will implement ASIP requirements in a timely manner to achieve the required service life and the objectives of the ASIP.

12c. The aircraft system program manager will ensure that the ASIP requirements are included in the procurement documentation for each phase of the system acquisition.

12d. AFWAL will develop recorder systems and equipment independent of aircraft development programs. The aircraft system program manager will determine the necessary and sufficient recorder system to be installed in the optimum number of operational aircraft and provide individual usage

tracking capability during the operational phase. When existing standardized recording systems are not to be installed, the justification for using a nonstandardized system will be included in the ASIP master plan. The acquisition of the nonstandard equipment must be approved by ASD/ENFS.

12f. The aircraft system program manager will provide ASIP assistance to AFLC as required in the master plan or as may become necessary before PMRT. After PMRT, requests for ASIP assistance will be processed according to AFSCR 27-5. ASD is authorized direct communication with AFLC/ALCs on ASIP matters.

12g. The ASD/ENF, in conjunction with AFLC/LOE, will maintain and revise MIL-STD-1530 and referenced military specifications as appropriate.

12h. The aircraft system program manager will advise the AFLC and using command of the ASIP requirement for the system in acquisition.

12i. AFFDL, in conjunction with ASD/ENFS, will comply.

12j. The aircraft system PM will plan, develop, and manage the structural data collection program and the required computer applications software to be compatible with the ASIMIS.

12k. AFFDL, in conjunction with ASD/ENF, will comply.

13. HQ AFLC/LOE is OPR for overall ASIP policy and procedures. HQ AFLC/LOA is OPR for the management and surveillance of the implementation of the established ASIP modifications, inspections, and maintenance actions required to ensure structural integrity for AFLC assigned aircraft.

13a(1)(Added). ALC/MMSR will establish an ASIP manager for each ALC assigned aircraft. The designated system manager will participate fully with the ASIP manager in developing the master plan and implementing the necessary ASIP actions to maintain structural safety and durability for his assigned aircraft.

13a(2)(Added). Each ALC/MMSR will designate a single ASIP focal point to ensure that all ALC assigned aircraft ASIPs are consistent with the current policy and procedures, serve as the ALC point of contact for coordinating actions relating to overall ASIP efforts, and represent the ALC on special ASIP studies or projects with other Air Force and industry representatives.

13c. OC-ALC/AIA will serve as the central AFLC agency for processing, analyzing, and storing aircraft structural integrity data generated by airborne flight data recorders; individual aircraft tracking records and forms; monitoring devices (such as counting accelerometers and strain recorders); and applicable maintenance data collection systems prescribed in AFLCR 23-9 and AFLCR 80-2.

13d. The ASIP manager, in conjunction with the system manager, will establish the recorder and tracking programs, including the necessary reporting procedures, for assigned aircraft. The reporting procedure will be coordinated with the participating commands to ensure that the most efficient method is established. Management of the aircraft flight data recorder program will be according to AFLCR 80-2.

13e(1) The ASIP manager, in conjunction with the system manager, will ensure that the ASIP data collection and analysis efforts for the aircraft flight recorder program, as defined in AFLCR 80-2, provide accurate and timely information. Data quality will be reported in the Flight Recorder Program Status quarterly report (RCS: LOG-LO(Q)7606), using AFLC Form 193.

13e(2) The ASIP manager, in conjunction with the system manager, will establish and maintain a Structural Maintenance Control Program, or equivalent automated data processing program as applicable for each weapon system. These programs will provide the means to monitor individual aircraft structural modification/inspection requirements and to ensure the required actions are scheduled and accomplished before exceeding safety or economic limits.

13e(3) The ASIP manager will report significant changes in service life capability to HQ AFLC/LOE and each participating command. HQ AFLC/LOE will forward changes to the appropriate HQ USAF offices. The changes will also be documented in the ASIP master plan.

13f(Added). To facilitate control, management, and logistics support of recorder systems components, the ASIP manager will coordinate with OC-ALC/MMI all actions that could affect item management of recorder systems, such as installations, removals, or location changes.

OFFICIAL

LEW ALLEN, JR., General, USAF
Commander

DAVID M. HUDACK, Colonel, USAF
Director of Administration

F. M. ROGERS, General, USAF
Commander
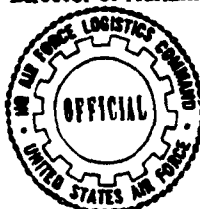
C. W. MORIN, Colonel, USAF
Director of Administration

1 Attachment
Format and Instructions for
ASIP Master Plan

A-3

(FORMAT–COVER PAGE)

AIRCRAFT STRUCTURAL INTEGRITY PROGRAM

MASTER PLAN

FOR

(Title and Weapon System Number)

(Date)

(Date of Latest Revision)

(Title and Location of Preparing Office)

Typed name and signature of
System Program Director or System Manager

Typed name and signature of
Chief System or Service Engineer

Typed name and signature of
Chief ASIP Engineer
ASD/ENFS (AFSC plans only)

A–4

FORMAT AND INSTRUCTIONS
FOR THE AIRCRAFT STRUCTURAL INTEGRITY PROGRAM MASTER PLAN

GENERAL

AFR 80-13 contains the requirement for an Aircraft Structural Integrity Program Master Plan.

The purpose of the Aircraft Structural Integrity Master Plan is to provide an overall guide and historical documentation for accomplishment of the various ASIP elements throughout the life cycle of the aircraft and will include both funding and support requirements. The responsible ASIP manager will ensure the adequacy and currency of the plan by conducting an annual review and provide revisions and/or validation in section 6, appendix F.

A dynamic master plan will allow the Air Force to: (1) enhance the evaluation of proposed engineering efforts during system acquisition, (2) focus on impending problems during development and acquisition, (3) make maximum use of the analyses and test results throughout the operational life of the system, (4) provide centralized program control and status, and (5) maintain a current digest of ASIP plans and status for dissemination to participating Air Force commands and agencies.

The master plan will provide a detailed description of how the ASIP tasks are to be implemented. The following outlines the information that will be contained in each section:

Table of Contents. This section of the plan will include: Table of Contents Frontispiece, Table of Changes, and Listing of the seven sections denoting all subparagraphs as applicable.

1.0 Introduction. This section of the plan will contain brief information relative to the aims of the particular structural integrity program, updating procedures, scope, background of the aircraft development, description of the aircraft and its models, three view drawings, pertinent load factor, weight, etc., data, and other general discussions. (See appendix A for detailed information.)

2.0 Summary. The plan will contain a summary section that briefly presents the important developments of the particular structural integrity program. This section of the plan will address such items as deviations identified as Not Programmed (see Checklist of ASIP Elements) and approved deviations from the general requirements; possible, or past, or current problems; schedule slippages, etc. (See appendix B for detailed information.)

3.0 Discussion of ASIP by Task. This section of the plan will discuss the weapon system application of each element contained within the five major ASIP tasks as specified in MIL-STD-1530, table 1. The discussions will be in summary form with supporting detailed information placed in appendix C. Further details concerning the content of section 3 are contained in the following subparagraphs.

3.1 Task I, Design Information. This section will contain individual subparagraphs for the elements of Structural Design Criteria, Damage Tolerance and Durability Control Plans, Selection of Materials, Processes and Joining Methods, Design Service Life, and Design Usage (MIL-STD-1530, section 5.1). The information to be provided in each element will concern the scope and application, deviations, problem areas, status (indicating amount completed), and schedule slippage.

3.2 Task II, Design Analysis and Development Tests. This section will contain individual subparagraphs for the elements of Materials and Joint Allowables, Load Analysis, Design Service Loads Spectra, Design Chemical/Thermal Environment Spectra, Stress Analysis, Damage Tolerance Analysis, Durability Analysis, Sonic Analysis, Vibration Analysis, Flutter Analysis, Nuclear Weapons Effects Analysis, Nonnuclear Weapons Effects Analysis, and Design Development Tests (MIL-STD-1530, section 5.2). The information to be provided in each element will concern the scope and application, deviations, analyses and testing problems, status (indicating amount completed), and schedule slippage.

3.3 Task III, Full-Scale Testing. This section will contain individual subparagraphs for the elements of Static Tests, Durability Tests, Damage Tolerance Tests, Flight and Ground Operations Tests, Sonic Tests, Flight Vibration Tests, Interpretation and Evaluation of Test Results (MIL-STD-1530, section 5.3). The information to be provided in each element will concern scope and application, deviations, significant testing problems, test results and evaluation, status (indicating amount completed), and schedule slippage.

3.4 Task IV, Force Management Data Package. This section will contain individual subparagraphs for the elements of Final Analyses, Strength Summary, Force Structural Maintenance Plan, Loads/Environment Spectra Survey, and Individual Airplane Tracking

Program (MIL-STD-1530, section 5.4). The information to be provided in each element will concern scope and application, deviations, restrictions imposed, actions needed to remove any restrictions, ASIMIS interface, data acquisition systems, economic/sensitivity studies, status (indicating amount completed), and schedule slippage.

3.5 Task V, Force Management. This section will contain individual subparagraphs for the elements of Loads Environment Spectra Survey, Individual Airplane Tracking Data, Individual Airplane Maintenance Times, and Structural Maintenance Records (MIL-STD-1530, section 5.5). The information to be provided in each element will concern scope and application, deviations, economic analyses, status (indicating amount completed), and schedule slippage. The critical areas and inspection periods to be cited will be restricted to those identified in Task IV and appropriate service revealed structural deficiencies.

4.0 Schedules, Responsibilities, and Flow Diagrams. The plan will contain specific schedules, responsibilities, flow diagrams, and other information needed to define the scope and operation of the ASIP. (See appendix D for detailed information.) This information will include but not be limited to:
(1) Checklist of ASIP Elements (attached).
(2) ASIP Flow Diagram showing the particular system program status on figures 1-3 of MIL-STD-1530.
(3) ASIP Master Schedule.
(4) Delineation of ASIP responsibilities (AFSC, AFLC, and using command) together with milestones.
(5) Detail schedules and flow diagrams for the actual operational usage program (recorder procurement and installation, data collection, ASIMIS software interface, storage, dissemination, and analysis).
(6) Modification programs. Discussion of requirement and schedule for structural modification resulting from the findings of any aspect of the ASIP.

5.0 Funding. The plan will include the costs for the ASIP. Subparagraph 5.1 will contain cost data supplied by the contractor. Subparagraph 5.2 will contain organic cost data supplied by the internal Air Force activity. These costs will include initial estimates together with updated cost information and when possible will be provided separately for each element of ASIP. The costs will be presented both for actual expenditures and projected requirements as a function of fiscal year for the next 5 years. Additional cost information will be provided as necessary and available. (See appendix E for detailed information.)

6.0 Appendices. The appendices will include the supporting data, rationale, decisions, engineering detail, etc., necessary to complement the summary of writeups presented in sections 1.0 through 5.0 of the plan. The appendices will also contain the annual revisions and/or validation required by AFR 80-13, paragraph 5b(3). The individual appendices will include the following detailed information as outlined below:

Appendix A—Section 1.0 supporting data will include:

—Brief history of development

—Distribution of aircraft by command by mission, design, series (MDS).
—Flight hour distribution by MDS; identify high time aircraft and force average.

—Flight hour distribution by major mission type.

—Principal aircraft dimensions.

—Illustration of major structural components and associated coordinates (numbered wing stations, etc.).

—Landing gear master plan (as applicable).

Appendix B—Section 2.0 supporting data will include:

—Rationale, discussion of background, impact on the force and copies of official HQ USAF documentation for all approved deviations. For each ASIP element designated "Not Programmed," discuss rationale, background, impact on the force, and ASIP objectives, and provide copies of any official documentation.

—Brief discussion of in-service problems, fixes, important inspections, and findings.

—Tabular summary of safety and economic life limits by structural detail. The details to be reported will be restricted to those identified in Task IV and appropriate service revealed structural deficiencies.

Appendix C

Task I—Section 3.0 supporting data for elements of Task I will include: basic structural design criteria; design mission profiles and mission mix; discussion of the design approach used to ensure structural safety and durability; damage tolerance and durability control plan; and rationale used in the

selection of materials, processes, and joining methods. See Task I, section 7, for applicable bibliography of reports.

Task II—Supporting data for elements of Task II will include a discussion of critical points in the design envelope specifying affected major structural component and results of design development tests. See Task II, section 7, for applicable bibliography of reports.

Task III—Supporting data for elements of Task III will include a discussion and evaluation of all test results, identification and illustrations of critical areas of the airframe, impacts resulting from correction of deficiencies, and results of post test inspections. See Task III, section 7, for applicable bibliography of reports.

Task IV—Supporting data for elements of Task IV will include structural limitations and capabilities as functions of the important operational perimeters (airspeed, altitude, etc.), inspection and modification requirements and the economic life of the airframe, results of tradeoff studies, type and number of multichannel recorders planned and installed, parameters being measured, data quantities obtained, method of tracking individual aircraft, ASIMIS interface provisions, and force sampling plan that includes required data quantities and hardware management plan. See Task IV, section 7, for applicable bibliography of reports.

Task V—Supporting data for elements of Task V will include: impact of mission or usage changes on force structural safety or economic life, status of the loads/environment spectra survey, status of individual airplane tracking data, and maintenance times and

records. See Task V, section 7, for applicable bibliography of reports.

Appendix D—Section 4.0 supporting data will include:

—Detailed schedules and major milestones of the ASIP elements.

—Major modifications and TCTOs, cite problems, corrective action, number in force affected, status.

Appendix E—Section 5.0 supporting data will include:

—Accumulated and projected cost of ASIP detailed by element if available.

—Funds and organic resources both expended and planned to implement major modifications and repairs.

Appendix F—Validation. This appendix will contain the annual validation if applicable and the coordination sheet for the initial plan and each revision.

Appendix G—ASIP Master Plan -Distribution. This appendix will contain the distribution list of the initial Master Plan and each revision.

Appendix H—As Required.

7.0 Bibliography. Master list of all documents referenced herein, listed by section and ASIP task (see appendix C).

CHECKLIST OF ASIP ELEMENTS

ELEMENT   STATUS

Task I

Structural Design Criteria
Damage Tolerance and Durability Control Plans
Selection of Materials, Processes and Joining Methods
Design Service Life and Design Usage

■■

Task II

Materials and Joint Allowables
Load Analysis
Design Service Loads Spectra
Design Chemical/Thermal Environment Spectra
Stress Analysis
Damage Tolerance Analysis
Durability Analysis
Sonic Analysis
Vibration Analysis
Flutter Analysis
Nuclear Weapons Effects Analysis
Nonnuclear Weapons Effects Analysis
Design Development Tests

■■

Task III

Static Tests
Durability Tests
Damage Tolerance Tests
Flight and Ground Operations Tests
Sonic Tests
Flight Vibration Tests
Flutter Tests
Interpretation and Evaluation of Test Results

■■

Task IV

Final Analyses
Strength Summary
Force Structural Maintenance Plan
Loads/Environment Spectra Survey (IV)
Individual Airplane Tracking Program (IV)

■■

Task V

Loads/Environment Spectra Survey (V)
Individual Airplane Tracking Data (V)
Individual Airplane Maintenance Times
Structural Maintenance Records

■■■

NOTES:
       For status enter:
       P = Programmed or NP = Not Programmed
       A = Active or C = Effort Completed

For all elements listed NP and all elements for which a deviation has been granted, cite the appropriate paragraph of appendix B.

For example, if the stress analysis is programmed but not initiated, the status would be programmed (1), if not programmed or a deviation granted, (2), and if initiated the status would be active.

ELEMENT	STATUS
(1) Stress Analysis	P
(2) Stress Analysis (Paragraph _____)	NP

Research and Development

AIRCRAFT STRUCTURAL INTEGRITY PROGRAM

This regulation establishes the Air Force Aircraft Structural Integrity Program (ASIP), explains the concept, and outlines the program objectives. It defines the policy, responsibilities and procedures to be followed by appropriate major commands in establishing, implementing, and utilizing the ASIP.

1. Explanation of Terms:

a. Required Service Life. The total number of operating hours of a specified mission spectrum throughout which an aircraft structure must be capable of operating safely and economically to satisfy the programmed use of that mission-design-series (MDS) aircraft force.

b. Service Life Capability. The total number of operating hours of the specified mission spectrum throughout which an aircraft structure has been determined by test and analysis to be capable of operating safely and economically.

2. Concept of the Aircraft Structural Integrity Program.

The ASIP is a time-phased set of required actions which are performed at the optimum time during the life cycle of an aircraft system, to insure that the aircraft's Service Life Capability is at least equal to its Required Service Life. Timely identification, scheduling and conduct of critical structural tests is required during full scale development of aircraft systems to minimize the need for structural retrofit of large numbers of aircraft, and to establish an orderly schedule of inspections and replacement or repair actions needed to maintain the structural integrity of the airframe.

3. Objectives of the ASIP.

The objectives of this program are to:

a. Establish, evaluate, and substantiate the structural integrity (airframe strength, rigidity, damage tolerance, durability, and service life capability) of aircraft structures.

b. Acquire, evaluate and utilize operational usage data to provide a continual update of the in-service structural integrity of the aircraft.

c. Provide quantitative information for decisions regarding force structure planning, modification priorities, and related operational and support decisions.

d. Provide a basis to improve structural criteria and methods of design, evaluation, and substantiation for future aircraft systems.

4. Application of Requirements.

The detailed technical requirements for an ASIP must be as contained in MIL-STD-1530, Aircraft Structural Integrity Program, Airplane Requirements. An ASIP is to be applied to each USAF aircraft as follows:

a. A complete ASIP, as described in MIL-STD-1530, is applied to all manned aircraft developed by the Air Force. For unmanned vehicles, only those elements will be applied that are necessary to insure sufficient structural safety and durability to meet the intended use of the airframe.

b. ASIP requirements will be applied as necessary to insure structural safety and determine the service life capability for:

(1) Current operational aircraft.

(2) Aircraft used, but not originally developed, by the Air Force.

(3) Air Force aircraft modified for or directed to new missions.

c. ASIP requirements must be applied as necessary to provide flight safety during prototype evaluation. A complete ASIP will be applied to any follow-on aircraft developed by the Air Force and will be accounted for in the prototype evaluation.

d. The ASIP requirements for Grant Aid, and Foreign Military Sales (FMS) aircraft are subject to the requirements of AFR 400-12 and AFM 400-3, and the structural integrity programs for these aircraft will be directed by HQ USAF on a case-by-case basis.

5. The ASIP Master Plan.

The ASIP manager will prepare a master plan for each aircraft system being developed or used by the Air Force.

a. This plan will:

(1) Incorporate the requirements of this regulation, MIL-STD-1530, and other appropriate documents into a meaningful system structural integrity program.

Supersedes AFR 80-13, 31 July 1969. (For summary of revised, deleted, or added material, see signature page.)
OPR: RDP
OCR: LGY
DISTRIBUTION: F

(2) Cover the entire life cycle of the aircraft through operational phase-out.

(3) Include the aircraft historical data, required service life, service life capability, and a detailed description of how the ASIP tasks are to be implemented.

(4) Record the aircraft design and test background and the official approval documentation that authorizes deviations from this regulation and MIL-STD-1530.

b. The ASIP manager will:

(1) Coordinate the plan and any request for deviations to it with each participating command (and the National Guard Bureau if applicable) before submitting them for approval.

(2) Document any unresolved issues and forward them with the proposed plan.

(3) Revise it as necessary to keep it current, and revalidate it annually.

6. Assignment of ASIP Management Responsibility. The command (AFSC or AFLC) which has program management responsibility for the system will normally have ASIP management responsibility as well. In some instances, however, it may be more desirable for AFSC to retain some of the ASIP management responsibility after transfering program management responsibility to AFLC. Therefore, the joint AFSC/AFLC Program Management Responsibility Transfer Plan for each system will document the specific ASIP responsibilities for each command, as mutually agreed upon by AFLC and AFSC, or as directed by HQ USAF. The individual responsibilities of HQ USAF, AFSC, AFLC, and the operating commands are specified below:

a. For systems under development, the ASIP requirements will be implemented as an integral part of the total engineering effort in the acquisition of an aircraft weapon system.

(1) The ASIP manager will translate the requirements of this regulation and MIL-STD-1530 into meaningful requirements for each aircraft and will document these in the master plan. The master plan must be approved before full-scale development begins.

(2) These requirements must be included in the procurement documentation for each aircraft in the conceptual prototype (if applicable), validation, full-scale development or production phases.

b. For systems not developed by the Air Force, but which the Air Force intends to use, the ASIP requirement will be an integral part of the evaluation and selection process. The master plan will be approved before the production and purchase decision is made.

c. For systems already in use, but which have not had the full ASIP requirements accomplished and documented, the ASIP manager will:

(1) Determine what part of the total program is essential to establish structural safety and remaining service life capability; and

(2) Submit the master plan for approval as soon as possible.

d. For systems which are to be modified for (or directed to) a new mission, a revised ASIP master plan will be approved before fleet modifications or regular operations begin under the new mission spectrum.

7. Obtaining Approval of the ASIP. The command which has program management responsibility will:

a. Document the proposed ASIP in the ASIP master plan, and submit the coordinated plan to HQ USAF for approval.

b. Submit requests for deviations to the HQ USAF office that has program responsibility for the specific aircraft system (RDP or LGY). Explain and justify the request fully in the proposed master plan. Approved deviations must be fully documented in the master plan. Revisions to MIL-STD-1530 require HQ USAF/RDP approval.

8. ASIP Documentation. Send an information copy of the approved ASIP master plan to each of the following HQ USAF directorates: RDP; RDQ; LGY; XOO; PRP (and LGF, for aircraft in Security Assistance programs) and to the OPR for the ASIP in each participating operating command.

9. ASIP Funding. The ASIP manager will budget and fund ASIP activities in accordance with AFM 172-1, USAF Budget Manual, which identifies the proper chargeable accounts.

10. Responsibilities of all Air Force Commands and Agencies:

a. Prepare and submit data and perform analyses and tests for all Air Force aircraft systems as required by the master plan for that system.

b. Implement the requirements of this regulation by issuing detailed documentation which specifies the command ASIP responsibilities and tasks.

c. Keep implementing documents current.

11. Responsibilities of HQ USAF:

a. Exercise surveillance over the ASIP for aircraft operated by USAF, Grant Aid, and FMS recipient countries and provide guidance as appropriate.

A-11

b. Evaluate requests for deviations from the provisions of this regulation and grant approval where appropriate.

c. Have approval authority for necessary revisions to MIL-STD-1530.

d. Have approval authority for all ASIP master plans.

e. Utilize and consider ASIP information in force structure planning and modification prioritization and implementation.

f. Provide the Required Service Life for all aircraft systems.

12. Responsibilities of AFSC. This command will establish an OPR for command-wide management of this program and will:

a. Appoint an ASIP manager for each aircraft system being acquired or used by the Air Force until program management responsibility is transferred to AFLC.

b. Implement ASIP requirements in a timely manner as an integral part of the total weapon system acquisition engineering.

c. Insure that ASIP requirements are included in the procurement documentation for each system in the acquisition life cycle.

d. Develop recorder systems and other devices and equipment to monitor loads or environment spectra of operational aircraft. Procure and install recorder systems in a portion (10 to 20 percent) of operational aircraft and provide individual usage tracking capability for operational aircraft, for which AFSC is ASIP manager. Wherever possible, existing standardized recording system designs are to be utilized and installed during acquisition or production phase.

f. Provide ASIP assistance to AFLC as required.

g. Maintain and revise MIL-STD-1530 and referenced military specifications as appropriate to reflect technological advances or improvements. Obtain AFLC coordination and HQ USAF approval of revisions to MIL-STD-1530.

h. Advise appropriate system program offices, AFLC, Operating Commands, and other management organizations of ASIP requirements.

i. Develop advanced data reduction and analysis techniques for evaluation of operational usage and fleet experience data.

j. Plan, develop, and manage the structural data collection program and the required computer applications software to be compatible with the ASIMIS as required.

k. Develop structural design criteria and methods for evaluating and substantiating airframe safety and durability for future aircraft systems.

13. Responsibilities of AFLC. This command will establish an OPR for command wide management of this program and will:

a. Appoint an ASIP manager on each aircraft system for which program management responsibility has been transferred from AFSC.

b. Maintain up-to-date copies of the master plan for each aircraft for which it is the ASIP manager.

c. Establish, coordinate with participating commands, and operate the Aircraft Structural Integrity Management Information System (ASIMIS).

d. If not previously accomplished, procure and install recorder systems in a portion (10 to 20 percent) of operational aircraft and provide individual usage tracking capability, as appropriate, for operational aircraft, for which AFLC is the ASIP manager.

e. Establish procedures for periodic reviews of each MDS aircraft's structural integrity program, to verify that:

(1) The required data collection and analysis effort are effective and operating efficiently.

(2) The fleet inspection and modification programs are on schedule.

(3) All significant changes in aircraft service life capability are reported to HQ USAF/RDP, RDQ, LGY, XOO, XOS, and PRP and to each participating command.

14. Responsibilities of the ASIP Manager:

a. Establish the aircraft system ASIP as outlined here, and coordinate with each participating command as required.

b. Prepare the master plan, coordinate it with participating commands, obtain HQ USAF approval, and revise it as necessary to keep it current; also, conduct an annual review of the plan and inform all participating commands of the results.

c. Budget for and fund the approved ASIP.

d. Implement the ASIP defined by the approved Master Plan.

e. Advise HQ USAF/RDP, RDQ, LGY, XOO, XOS, and PRP, and each participating command of the impact upon structural integrity of an aircraft system when its mission is changed.

f. Establish ASIMIS support requirements, review and analyze ASIMIS reports and initiate corrective actions where required.

g. Insure that structural data collection programs and the required computer applications software are developed in accordance with the master plan and are compatible with ASIMIS as required.

h. Establish and document the life cycle inspection and modification actions and schedules

A-12

required to maintain the structural integrity of each aircraft system.

5. Responsibilites of the Operating Commands. Each of these commands will establish an OPR for command-wide management of this program, and will:

a. Provide data on system utilization, operational usage and fleet experience to the aircraft system ASIP manager when requested.

b. Advise the ASIP manager of contemplated changes in mission and operational environment from that for which the aircraft was designed.

c. Install, operate and maintain ASIP hardware as required; prepare and process actual operational usage data in accordance with governing directives and the ASIP master plan; provide guidance and monitor unit level performance to insure that an efficient data collection system is functioning in support of each weapon system ASIP.

d. Indoctrinate aircrews and recommend revisions to aircraft flight manuals (-1) to make known the impact that mission profiles, maneuvers and techniques have on aircraft structural life.

BY ORDER OF THE SECRETARY OF THE AIR FORCE

OFFICIAL

DAVID C. JONES, General, USAF
Chief of Staff

JAMES J. SHEPARD, Colonel, USAF
Director of Administration

SUMMARY OF REVISED, DELETED, OR ADDED MATERIAL
This is a complete revision of this regulation. It eliminates the need for regular interval formal reporting; clarifies and amplifies major command responsibilities; and updates the program to reflect the changing design philosophies in government and industry.

MILITARY STANDARD

AIRCRAFT STRUCTURAL INTEGRITY PROGRAM,
AIRPLANE REQUIREMENTS

FSC 15GF

MIL-STD-1530A(11)

Airplane Structural Integrity Program, Airplane Requirements

MIL-STD-1530A(11)

1. This Military Standard is approved for use by all Departments and Agencies of the Department of Defense.

2. Recommended corrections, additions, or deletions should be addressed to Aeronautical Systems Division, ASD/ENFS, Wright-Patterson Air Force Base, Ohio 45433.

MIL-STD-1530A(11)

CONTENTS

CONTENTS (CONT'D)

CONTENTS (CONT'D)

1. SCOPE

1.1 Purpose. The purpose of this standard is to describe the Air Force Aircraft Structural Integrity Program, define the overall requirements necessary to achieve structural integrity of USAF airplanes, and specify acceptance methods of contractor compliance. This standard shall be used by:

a. Contractors in conducting the development of an airframe for a particular weapon or support system

b. Government personnel in managing the development, production, and operational support of a particular airplane system throughout its life cycle.

1.2 Applicability. The degree of applicability of the various portions of this standard may vary between airplane systems as specified in 1.3.

1.2.1 Type of aircraft. This standard is directly applicable to manned power driven aircraft having fixed or adjustable fixed wings and to those portions of manned helicopter and V/STOL aircraft which have similar structural characteristics. Helicopter-type power transmission systems, including lifting and control rotors, and other dynamic machinery, and power generators, engines, and propulsion systems are not covered by this standard. For unmanned vehicles, certain requirements of this standard may be waived or factors of safety reduced commensurate with sufficient structural safety and durability to meet the intended use of the airframe. Waivers and deviations shall be specified in the contract specifications and shall have specific Air Force approval prior to commitment in the design.

1.2.2 Type of program. This standard applies to:

a. Future airplane systems

b. Airplane systems procured by the Air Force but developed under the auspices of another regulatory activity (such as the FAA or USN)

c. Airplanes modified or directed to new missions.

1.2.3 Type of structure. This standard applies to metallic and nonmetallic structures unless stated otherwise in the specifications referenced herein.

1.3 Modifications. The Air Force will make the decision regarding application of this standard and may modify requirements of this standard to suit system needs. The description of the modifications shall be documented in accordance with 5.1.1.

2. REFERENCED DOCUMENTS

2.1 <u>Issues of documents</u>. The following documents, of the issue in effect on date of invitation for bids or request for proposal, form a part of this standard to the extent specified herein:

SPECIFICATIONS

Military

MIL-I-6870	Inspection Program Requirements, Nondestructive, for Aircraft and Missile Materials and Parts
MIL-A-8860	Airplane Strength and Rigidity, General Specification for
MIL-A-8861	Airplane Strength and Rigidity, Flight Loads
MIL-A-8862	Airplane Strength and Rigidity, Landplane, Landing and Ground Handling Loads
MIL-A-8865	Airplane Strength and Rigidity, Miscellaneous Loads
MIL-A-8866	Airplane Strength and Rigidity, Reliability Requirements, Repeated Loads, and Fatigue
MIL-A-8867	Airplane Strength and Rigidity, Ground Tests
MIL-A-8869	Airplane Strength and Rigidity, Nuclear Weapons Effects
MIL-A-8870	Airplane Strength and Rigidity, Vibration Flutter and Divergence
MIL-A-8871	Airplane Strength and Rigidity, Flight and Ground Operations Tests
MIL-A-8892	Airplane Strength and Rigidity, Vibration
MIL-A-8893	Airplane Strength and Rigidity, Sonic Fatigue
MIL-R-83165	Recorder, Signal Data, MXU-553/A
MIL-C-83166	Converter-multiplexer, Signal Data, General Specification for
MIL-A-83444	Airplane Damage Tolerance Requirements

STANDARDS

Military

MIL-STD-499	Engineering Management
MIL-STD-882	System Safety Program for Systems and Associated Subsystems and Equipment, Requirements for
MIL-STD-1515	Fasteners to be Used in the Design and Construction of Aerospace Mechanical Systems
MIL-STD-1568	Materials and Processes for Corrosion and Prevention and Control in Aerospace Weapons Systems

HANDBOOKS

Military

MIL-HDBK-S	Metallic Materials and Elements for Aerospace Vehicle Structures
MIL-HDBK-17	Plastics for Flight Vehicles
MIL-HDBK-23	Structural Sandwich Composites

Air Force Systems Command Design Handbooks

DH 1-0	General
DH 1-2	General Design Factors
DH 2-0	Aeronautical Systems
DH 2-7	System Survivability

(Copies of specifications, standards, drawings and publications required by con-tractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 Other publications. The following document forms a part of this standard to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

Other Publications

MCIC-HB-01   Damage Tolerance Design Handbook

(Application for copies should be addressed to the Metals and Ceramics Infor-mation Center, Battelle Memorial Institute, Columbus, Ohio 43201.)

3. DEFINITIONS. Definitions will be in accordance with the documents listed in Section 2 and as specified herein.

3.1 Durability. The ability of the airframe to resist cracking (including stress corrosion and hydrogen induced cracking), corrosion, thermal degrada-tion, delamination, wear, and the effects of foreign object damage for a specified period of time.

3.2 Economic life. That operational life indicated by the results of the durability test program, i.e., test performance interpretation and evaluation in accordance with MIL-A-8867 to be available with the incorporation of Air Force approved and committed production or retrofit changes and supporting application of the force structural maintenance plan in accordance with this standard. In general, production or retrofit changes will be incorporated to correct local design and manufacturing deficiencies disclosed by test. It

will be assumed that the economic life of the test article has been attained with the occurrence of widespread damage which is uneconomical to repair and, if not repaired, could cause functional problems affecting operational readiness. This can generally be characterized by a rapid increase in the number of damage locations or repair costs as a function of cyclic test time.

3.3 Initial quality. A measure of the condition of the airframe relative to flaws, defects, or other discrepancies in the basic materials or introduced during manufacture of the airframe.

3.4 Structural operating mechanisms. Those operating, articulating, and control mechanisms which transmit structural forces during actuation and movement of structural surfaces and elements.

3.5 Damage tolerance. The ability of the airframe to resist failure due to the presence of flaws, cracks, or other damage for a specified period of unrepaired usage.

4. GENERAL REQUIREMENTS

4.1 Discussion. The effectiveness of any military force depends in part on the operational readiness of weapon systems. One major item of an airplane system affecting its operational readiness is the condition of the structure. The complete structure, herein referred to as the airframe, includes the fuselage, wing, empennage, landing gear, control systems and surfaces, engine mounts, structural operating mechanisms, and other components as specified in the contract specification. To maintain operational readiness, the capabilities, condition, and operational limitations of the airframe of each airplane weapon and support system must be established. Potential structural or material problems must be identified early in the life cycle to minimize their impact on the operational force, and a preventive maintenance program must be determined to provide for the orderly scheduling of inspections and replacement or repair of life-limited elements of the airframe.

4.1.1 The overall program to provide USAF airplanes with the required structural characteristics is referred to as the Aircraft Structural Integrity Program (ASIP). General requirements of the ASIP are to:

a. Establish, evaluate, and substantiate the structural integrity (airframe strength, rigidity, damage tolerance, and durability) of the airplane.

b. Acquire, evaluate, and utilize operational usage data to provide a continual assessment of the in-service integrity of individual airplanes.

c. Provide a basis for determining logistics and force planning requirements (maintenance, inspections, supplies, rotation of airp anes, system phaseout, and future force structure).

d. Provide a basis to improve structural criteria and methods of design, evaluation, and substantiation for future airplanes.

4.1.2 The majority of detail requirements are published in the referenced military specifications. This standard repeats some of these requirements for emphasis and contains additional requirements which are not currently included in the military specifications. Any differences in detail requirements that may exist between this standard and the referenced documents listed in Section 2 shall be brought to the immediate attention of the Air Force for resolution. The applicable specifications, including the latest revisions thereto, for a particular airplane shall be as stated in the contract specifications.

4.2 Requirements. ASIP consists of the following five interrelated functional tasks as specified in table 1 and figures 1, 2, and 3:

a. Task I (design information): Development of those criteria which must be applied during design so that the specific requirements will be met.

b. Task II (design analysis and development tests): Development of the design environment in which the airframe must operate and the response of the airframe to the design environment.

c. Task III (full scale testing): Flight and laboratory tests of the airframe to assist in determination of the structural adequacy of the design.

d. Task IV (force management data package): Generation of data required to manage force operations in terms of inspections, modifications, and damage assessments.

e. Task V (force management): Those operations that must be conducted by the Air Force during force operations to ensure damage tolerance and durability throughout the useful life of individual airplanes.

5. DETAIL REQUIREMENTS

5.1 Design information (Task I). The design information task encompasses those efforts required to apply the existing theoretical, experimental, applied research, and operational experience to specific criteria for materials selection and structural design for the airplane. The objective is to ensure that the appropriate criteria and planned usage are applied to an airplane design so that the specific operational requirements will be met. This task begins as early as possible in the conceptual phase and is finalized in subsequent phases of the airplane life cycle.

5.1.1 <u>ASIP master plan</u>. The contractor shall prepare an ASIP Master Plan in accordance with the detail requirements specified in the contract specifications. The purpose of the ASIP Master Plan is to define and document the specific approach for accomplishment of the various ASIP tasks throughout the life cycle of the airplane. The plan shall depict the time phased scheduling and integration of all required ASIP tasks for design, development, qualification, and tracking of the airframe. The plan shall include discussion of unique features, exceptions to the requirements of this standard and the associated rationale, and any problems anticipated in the execution of the plan. The development of the schedule shall consider all interfaces, impact of schedule delays (e.g., delays due to test failure), mechanisms for recovery programming, and other problem areas. The plan and schedules shall be updated annually and when significant changes occur. The ASIP Master Plan shall be subject to approval by the Air Force.

5.1.2 <u>Structural design criteria</u>. Detail structural design criteria for the specific airplane shall be established by the contractor in accordance with the requirements of the specifications as specified in 5.1.2.2. These specifications contain design criteria for strength, damage tolerance, durability, flutter, vibration, sonic fatigue, and weapons effects. The structural design criteria for damage tolerance and durability are further specified in 5.1.2.1 for special emphasis.

5.1.2.1 <u>Damage tolerance and durability design criteria</u>. The airframe shall incorporate materials, stress levels, and structural configurations which:

a. Allow routine in-service inspection

b. Minimize the probability of loss of the airplane due to propagation of undetected cracks, flaws, or other damage

c. Minimize cracking (including stress corrosion and hydrogen induced cracking), corrosion, delamination, wear, and the effects of foreign object damage.

Damage tolerance design approaches shall be used to insure structural safety since undetected flaws or damage can exist in critical structural components despite the design, fabrication, and inspection efforts expended to eliminate their occurrence. Durability structural design approaches shall be used to achieve Air Force weapon and support systems with low in-service maintenance costs and improved operational readiness throughout the design service life of the airplane.

5.1.2.1.1 <u>Damage tolerance</u>. The damage tolerance design requirements are specified in MIL-A-83444, and shall apply to safety-of-flight structure. Damage tolerance designs are categorized into two general concepts:

a. Fail-safe concepts where unstable crack propagation is locally contained through the use of multiple load paths or tear stoppers

b. Slow crack growth concepts where flaws or defects are not allowed to attain the size required for unstable rapid propagation.

Either design concept shall assume the presence of undetected flaws or damage, and shall have a specified residual strength level both during and at the end of a specified period of unrepaired service usage. The initial damage size assumptions, damage growth limits, residual strength requirements and the minimum periods of unrepaired service usage depend on the type of structure and the appropriate inspectability level.

5.1.2.1.2 <u>Durability</u>. The durability design requirements are specified in MIL-A-8866. The airframe shall be designed such that the economic life is greater than the design service life when subjected to the design service loads/ environment spectrum. The design service life and typical design usage require- ments will be specified by the Air Force in the contract specifications for each new airplane. The design objective is to minimize cracking or other structural or materj   degradation which could result in excessive maintenance problems or functional problems such as fuel leakage, loss of control effective- ness, or loss of cabin pressure.

5.1.2.2 <u>Structural design criteria requirements</u>. Using the requirements in the System specification and the referenced military specifications the con- tractor shall prepare the detailed structural design criteria for the particular airplane. These criteria and all elements thereof shall require approval by the Air Force. Detail structural design criteria are specified in AFSC DH 1-0 and DH 2-0 and in MIL-A-8860, MIL-A-8861, MIL-A-8862, MIL-A-8865, MIL-A-8866, MIL-A-8869, MIL-A-8870, MIL-A-8892, MIL-A-8893, and MIL-A-83444. Where appli- cable, specific battle damage criteria will be provided by the Air Force. These criteria will include the threat, flight conditions, and load carrying capability and duration after damage is imposed, etc. The structure shall be designed to these criteria and to other criteria as specified in AFSC DH 2-7.

5.1.3 <u>Damage tolerance and durability control plans</u>. The contractor shall prepare damage tolerance and durability control plans and conduct the result- ing programs in accordance with this standard, MIL-A-8866, and MIL-A-83444. The plans shall identify and define all of the tasks necessary to ensure compliance with the damage tolerance requirements as specified in 5.1.2.1.1 and MIL-A-83444, and the durability requirements as specified in 5.1.2.1.2 and MIL-A-8866. The plans and their individual elements shall require appro- val by the Air Force. The disciplines of fracture mechanics, fatigue, materials selection and processes, environmental protection, corrosion prevention and control, design, manufacturing, quality control, and nondestructive inspection are involved in damage tolerance and durability control. The corrosion pre- vention and control plan shall be in accordance with MIL-STD-1568. The plans shall include the requirement to perform damage tolerance and durability design concepts/material/weight/performance/cost trade studies during the early design phases to obtain low weight, cost effective designs which comply with the requirements of MIL-A-8866 and MIL-A-83444.

5.1.3.1 <u>Damage tolerance control plan</u>. The damage tolerance control plan shall include as a minimum the following tasks:

a. Basic fracture data (i.e., K_{IC}, K_C, K_{ISCC}, da/dn, etc.) utilized in the initial trade studies and the final design and analyses shall be obtained from existing sources or developed as part of the contract in accordance with 5.2.1.

b. A fracture critical parts list shall be established by the contractor in accordance with MIL-A-83444. The fracture critical parts list shall require approval by the Air Force and the list shall be kept current as the design of the airframe progresses.

c. Design drawings for the fracture critical parts shall identify critical locations and special processing (e.g., shot peening) and inspection requirements.

d. Complete nondestructive inspection requirements, process control requirements, and quality control requirements for fracture critical parts shall be established by the contractor and shall require approval by the Air Force. Nondestructive inspections shall comply with MIL-I-6870. This task shall include the proposed plan for certifying and monitoring subcontractor, vendor, and supplier controls.

e. The damage tolerance control plan shall include any special nondestructive inspection demonstration programs conducted in accordance with the requirements of MIL-A-83444.

f. Material procurement and manufacturing process specifications shall be developed and updated as necessary to minimize the possibility that basic materials and the resulting fracture critical parts have fracture toughness properties in the important loading directions which are less than those used in design.

g. Traceability requirements shall be defined and imposed by the contractor on those fracture critical parts that receive prime contractor or subcontractor in-house processing and fabrication operations which could degrade the design material properties.

h. Damage tolerance analyses, development testing, and full scale testing shall be performed in accordance with this standard, MIL-A-8867 and MIL-A-83444.

i. For all fracture critical parts that are designed for a degree of inspectability other than in-service noninspectable, the contractor shall define the necessary inspection procedures for field use for each appropriate degree of inspectability as specified in MIL-A-83444.

5.1.3.2 <u>Durability control plan</u>. The durability control plan shall include as a minimum the following tasks:

a. A disciplined procedure for durability design shall be implemented to minimize the possibility of incorporating adverse residual stresses, local design details, materials, processing, and fabrication practices into the airplane design and manufacture which could lead to cracking or failure problems (i.e., those problems which have historically been found early during durability testing or early in service usage). The durability control plan shall encompass the requirements specified in the durability detail design procedures of MIL-A-8866.

b. Basic data (i.e., initial quality distribution, fatigue allowables, etc.) utilized in the initial trade studies and the final design and analyses shall be obtained from existing sources or developed as part of the contract in accordance with 5.2.1.

c. A criteria for identifying durability critical parts shall be established by the contractor and shall require approval by the Air Force. It is envisioned that durability critical parts will be expensive, noneconomical-to-replace parts that are either designed and sized by the durability requirements of MIL-A-8866 or could be designed and sized by the requirements of MIL-A-8866 if special control procedures are not employed. A durability critical parts list shall be established by the contractor and shall be kept current as the design of the airframe progresses.

d. Design drawings for the durability critical parts shall identify critical locations and special processing and inspection requirements.

e. Material procurement and manufacturing process specifications shall be developed and updated as necessary to minimize the possibility that initial quality is degraded below that assumed in the design.

f. Experimental determination sufficient to estimate initial quality by microscopic or fractographic examination shall be required for those structural areas where cracks occur during full scale durability testing. The findings shall be used in the full scale test data interpretation and evaluation task as specified in 5.3.8 and, as appropriate, in the development of the force structural maintenance plan as specified in 5.4.3.

g. Durability analyses, development testing, and full scale testing shall be performed in accordance with this standard, MIL-A-8866, and MIL-A-8867.

5.1.4 Selection of materials, processes, and joining methods. Materials, processes, and joining methods shall be selected to result in a light-weight, cost-effective airframe that meets the strength, damage tolerance, and durability requirements of this standard and supporting specifications. A primary factor in the final selection shall be the results of the design concept/material/weight/cost trade studies performed as a part of the damage tolerance and durability control programs.

5.1.4.1 Structural materials, processes, and joining methods selection requirements. In response to the request for proposal, prospective contractors shall identify the proposed materials, processes, and joining methods to be used in each of the structural components and the rationale for the individual selections. After contract award and during the design activity, the contractor shall document the complete rationale used in the final selection for each structural component. This rationale shall include all pertinent data upon which the selections were based including the data base, previous experience, and trade study results. The requirements of AFSC DH 1-2, Sections 7A, paragraph entitled, Materials, and 7B, paragraph entitled, Processes, shall be met as applicable. The selection of fasteners shall be in accordance with MIL-STD-1515. The materials, processes, and joining method selections for fracture and durability critical parts shall require approval by the Air Force.

5.1.5 Design service life and design usage. The Air Force will provide the required design service life and typical design usage as part of the contract specifications. These data shall be used in the initial design and analysis of the airframe. The design service life and design usage will be established through close coordination between the procuring activity and the advanced planning activities (i.e., Hq USAF, Hq AFSC, Hq AFLC, and using commands). Design mission profiles and mission mixes which are realistic estimates of expected service usage will be established. It is recognized that special force management actions will probably be required (i.e., early retirement, early modification, or rotation of selected airplanes) if the actual usage is more severe than the design usage. All revisions in these data subsequent to contract negotiations shall be at the discretion of the Air Force but will require separate negotiations between the Air Force and contractor.

5.2 Design analyses and development tests (Task II). The objectives of the design analyses and development tests task are to determine the environments in which the airframe must operate (load, temperature, chemical, abrasive, vibratory and acoustic environment) and to perform preliminary analyses and tests based on these environments to design and size the airframe to meet the required strength, damage tolerance, and durability requirements.

5.2.1 Material and joint allowables. The contractor shall utilize as appropriate the materials and joint allowables data in MIL-HDBK-5, MIL-HDBK-17, 4IL-HDBK-23, and MCIC-HDBK-01 to support the various design analyses. Other data sources may also be used but will require approval by the Air Force.

For those cases where there are insufficient data available, the contractor shall formulate and perform experimental programs to obtain the data. Generation and analysis of test data shall meet the requirements of MIL-HDBK-5. The scope of these programs shall be defined by the prospective contractors in their responses to the request for proposal and shall require approval by the Air Force.

5.2.2 <u>Loads analysis</u>. The contractor shall comply with the detail requirements for loads analysis as specified in the contract specifications. The loads analysis shall consist of determining the magnitude and distribution of significant static and dynamic loads which the airframe may encounter when operating within the envelope established by the structural design criteria. This analysis consists of determining the flight loads, ground loads, powerplant loads, control system loads, and weapon effects. When applicable, this analysis shall include the effects of temperature, aeroelasticity, and dynamic response of the airframe.

5.2.3 <u>Design service loads spectra</u>. The contractor shall comply with the detail requirements for design service loads spectra in MIL-A-8866 as specified in the contract specifications. These spectra shall require approval by the Air Force. The purpose of the design service loads spectra is to develop the distribution and frequency of loading that the airframe will experience based on the design service life and typical design usage. The design service loads spectra and the design chemical/thermal environment spectra as specified in 5.2.4 will be used to develop design flight-by-flight stress/environment spectra as appropriate to support the various analyses and test tasks specified herein.

5.2.4 <u>Design chemical/thermal environment spectra</u>. The contractor shall comply with the detail requirements for design chemical/thermal environment spectra in MIL-A-8866 as specified in the contract specifications. These spectra shall require approval by the Air Force. These spectra shall characterize each environment (i.e., intensity, duration, frequency of occurrence, etc.).

5.2.5 <u>Stress analysis</u>. The contractor shall comply with the detail requirements for stress analysis as specified in the contract specifications. This analysis shall require approval by the Air Force. The stress analysis shall consist of the analytical determination of the stresses, deformation, and margins of safety resulting from the external loads and temperatures imposed on the airframe. The ability of the airframe to support the critical loads and to meet the specified strength requirements shall be established. In addition to verification of strength the stress analysis shall be used as a basis for durability and damage tolerance analyses, selection of critical structural components for design development tests, material review actions, and selection of loading conditions to be used in the structural testing.

The stress analysis shall also be used as a basis to determine the adequacy of structural changes throughout the life of the airplane and to determine the adequacy of the structure for new loading conditions that result from increased performance or new mission requirements. The stress analysis shall be revised to reflect any major changes to the airframe or to the loading conditions applied to the airframe.

5.2.6 <u>Damage tolerance analysis</u>. The contractor shall comply with the detail requirements for damage tolerance analysis in MIL-A-83444 as specified in the contract specifications. This analysis shall require approval by the Air Force. The purpose of this analysis is to substantiate the ability of the structural components to meet the requirements of MIL-A-83444.

5.2.6.1 <u>Analysis procedures</u>. The design flight-by-flight stress/environment spectra based on the requirements of 5.2.3 and 5.2.4 shall be used in the damage growth analysis and verification tests. The calculations of critical flaw sizes, residual strengths, safe crack growth periods, and inspection intervals shall be based on existing fracture test data and basic fracture allowables data generated as a part of the design development test program. The effect of variability in fracture properties on the analytical results shall be accounted for in the damage tolerance design.

5.2.7 <u>Durability analysis</u>. The contractor shall comply with the detail requirements for durability analysis in MIL-A-8866 as specified in the contract specifications. This analysis shall require approval by the Air Force. The purpose of this analysis is to substantiate the ability of the structure to meet the requirements of MIL-A-8866.

5.2.7.1 <u>Analysis procedures</u>. The design flight-by-flight stress/environment spectra based on the requirements of 5.2.3 and 5.2.4 shall be used in the durability analysis and verification tests. The analysis approach shall account for those factors affecting the time for cracks or equivalent damage to reach sizes large enough to cause uneconomical functional problems, repair, modification, or replacement. These factors shall include initial quality and initial quality variations, chemical/thermal environment, load sequence and environment interaction effects, material property variations, and analytical uncertainties. In addition to providing analytical assurance of a durable design, the durability analysis will provide a basis for development of test load spectra to be used in the design development and full scale durability tests.

5.2.8 <u>Sonic durability analysis</u>. The contractor shall comply with the detail requirements for sonic durability analysis in MIL-A-8893 as specified in the contract specifications. This analysis shall require approval by the Air Force. The objective of the sonic durability analysis is to ensure that the airframe is resistant to sonic durability cracking throughout the design service life.

The analysis shall define the intensity of the acoustic environment from potentially critical sources and shall determine the dynamic response, including significant thermal effects. Potentially critical sources include but are not limited to powerplant noise, aerodynamic noise in regions of turbulent and separated flow, exposed cavity resonance, and localized vibratory forces.

5.2.9 Vibration analysis. The contractor shall comply with the detail requirements for vibration analysis in MIL-A-8892 as specified in the contract specifications. This analysis shall require approval by the Air Force. The design shall control the structural vibration environment and the analysis shall predict the resultant environment in terms of vibration levels in various areas of the airplane such as the crew compartment, cargo areas, equipment bays, etc. The structure in each of these areas shall be resistant to unacceptable cracking as specified in 5.2.7.1 due to vibratory loads throughout the design service life. In addition, the design shall control the vibration levels to that necessary for the reliable performance of personnel and equipment throughout the design life of the airplane.

5.2.10 Flutter and divergence analysis. The contractor shall comply with the detail requirements for flutter and divergence analysis in MIL-A-8870 as specified in the contract specifications. This analysis shall require approval by the Air Force. The analysis shall consist of determination of the airplane flutter and divergence characteristics resulting from the interaction of the aerodynamic, inertia, and elastic characteristics of the components involved. The objective of the analysis is to substantiate the ability of the airplane structure to meet the specified flutter and divergence margins. Flutter analysis for failure modes as agreed to by the Air Force and the contractor shall also be conducted.

5.2.11 Nuclear weapons effects analyses. The contractor shall comply with the detail requirements for nuclear weapons effects analyses in MIL-A-8869 as specified in the contract specifications. These analyses shall require approval by the Air Force. The objectives of the nuclear weapons effects analyses are to:

a. Verify that the design of the airframe will successfully resist the specified environmental conditions with no more than the specified residual damage

b. Determine the structural capability envelope and crew radiation protection envelope for other degrees of survivability (damage) as may be required.

The contractor shall prepare detail design criteria and shall conduct the nuclear weapons effects analyses for transient thermal, overpressure, and gust loads and provide the substantiation of allowable structural limits on the structures critical for these conditions. The contractor shall also prepare and report the nuclear weapons effects capability envelope, including crew radiation protection, for a specified range of variations of weapon delivery trajectories, weapon size, aircraft escape maneuvers, and the resulting damage limits.

5.2.12 <u>Non-nuclear weapons effects analysis</u>. The contractor shall comply with the detail requirements for non-nuclear weapons effects analysis in AFSC DH 2-7 as specified in the contract specifications. This analysis shall require approval by the Air Force.

5.2.13 <u>Design development tests</u>. The contractor shall comply with the detail requirements for design development tests in MIL-A-8867, MIL-A-8870, MIL-A-8892, and MIL-A-8893 as specified in the contract specifications. The design development test program shall require approval by the Air Force. The objectives of the design development tests are to establish material and joint allowables; to verify analysis procedures; to obtain early evaluation of allowable stress levels, material selections, fastener systems, and the effect of the design chemical/thermal environment spectra; to establish flutter characteristics through wind tunnel tests; and to obtain early evaluation of the strength, durability (including sonic durability), and damage tolerance of critical structural components and assemblies. Examples of design development tests are tests of coupons; small elements; splices and joints; panels; fittings; control system components and structural operating mechanisms; and major components such as wing carry through, horizontal tail spindles, wing pivots, and assemblies thereof. Prospective contractors shall establish the scope of their proposed test program in their response to the request for proposal. After contract award and during the design analysis task, the contractor(s) shall finalize the plans and submit them to the Air Force for approval. The contractor shall revise and maintain approved updated versions of the test plans as the design develops. The plans shall consist of information such as rationale for selection of scope of tests; description of test articles, procedures, test loads and test duration; and analysis directed at establishing cost and schedule trade-offs used to develop the program.

5.3 <u>Full scale testing (Task III)</u>. The objective of this task is to assist in determining the structural adequacy of the basic design through a series of ground and flight tests.

5.3.1 <u>Static tests</u>. The contractor shall comply with the detail requirements for static tests in MIL-A-8867 as specified in the contract specifications. Prior to initiation of testing, the test plans, procedures, and schedules shall be subject to approval by the Air Force. The static test program shall consist of a series of laboratory tests conducted on an instrumented airframe that simulates the loads resulting from critical flight and ground handling conditions. Thermal environment effects shall be simulated along with the load application on airframes where operational environments impose significant thermal effects. The primary purpose of the static test program is to verify the design ultimate strength capabilities of the airframe. Full scale static tests to design ultimate loads shall be required except:

a. Where it is shown that the airframe and its loading are substantially the same as that used on previous aircraft where the airframe has been verified by full scale tests

b. Where the strength margins (particularly for stability critical structure) have been demonstrated by major assembly tests.

When full scale ultimate load static tests are not performed, it shall be a program requirement to conduct a strength demonstration proof test. Deletion of the full scale ultimate load static tests shall require approval by the Air Force. Functional and inspection type proof test requirements shall be in accordance with MIL-A-8867.

5.3.1.1 Schedule requirement. The full scale static tests shall be scheduled such that the tests are completed in sufficient time to allow removal of the 80 percent limit restrictions on the flight test airplanes in accordance with MIL-A-8871 and allow unrestricted flight within the design envelope on schedule.

5.3.2 Durability tests. The contractor shall comply with the detail require- ments for durability tests in MIL-A-8867 as specified by the contract specifi- cations. Prior to initiation of testing, the test plans, procedures, and schedules shall require approval by the Air Force. Durability tests of the airframe shall consist of repeated application of the flight-by-flight design service loads/environment spectra. The objectives of the full scale durability tests are to:

a. Demonstrate that the economic life of the test article is equal to or greater than the design service life when subjected to the design service loads/environment spectra

b. Identify critical areas of the airframe not previously identified by analysis or component testing

c. To provide a basis for establishing special inspection and modification requirements for force airplanes.

5.3.2.1 Selection of test articles. The test article shall be an early Full Scale Development (FSD) or Research Development Test & Evaluation (RDT&E) airframe and shall be as representative of the operational configuration as practical. If there are significant design, material, or manufacturing changes between the test article and production airplanes, durability tests of an additional article or selected components and assemblies thereof shall be required.

5.3.2.2 Schedule requirements. The full scale airframe durability test shall be scheduled such that one lifetime of durability testing plus an inspection of critical structural areas in accordance with 5.3.2.2.a and b shall be com- pleted prior to full production go ahead decision. Two lifetimes of durability testing plus an inspection of critical structural areas in accordance with 5.3.2.3.a and b shall be scheduled to be completed prior to delivery of the first production airplane. If the economic life of the test article is reached

prior to two lifetimes of durability testing, sufficient inspection in accord-
ance with 5.3.2.3.a and b and data evaluation shall be completed prior to
delivery of the first production airplane to estimate the extent of required
production changes and retrofit. In the event the original schedule for the
production decision and production delivery milestones become incompatible
with the above schedule requirements, a study shall be conducted to assess
the technical risk and cost impacts of changing these milestones. An important
consideration in the durability test program is that it be completed at the
earliest practical time. This is needed to minimize force modifications due
to deficiencies found during testing. To this end the following needs to be
accomplished:

a. Timely formulation of the test load spectra

b. Early delivery of the test article

c. Early establishment of managerial and contractual procedures for minimizing
downtime in the event of a test failure.

Truncation, elimination, or substitution of load cycles in the test spectra
to reduce test time and cost will be allowed. The contractor shall define
by analysis and laboratory experiment the effect of any proposed truncation
on the time to reach detrimental crack sizes to comply with the durability
and damage tolerance requirements of MIL-A-8866 and MIL-A-83444 respectively.
The results of these analyses and experiments shall be used to establish the
final test spectra and, as necessary, to interpret the test results. The
final test spectra shall require approval by the Air Force.

5.3.2.3 <u>Inspections</u>. Major inspection programs shall be conducted as an
integral part of the full scale airframe durability test. The inspection
programs shall require approval by the Air Force. These inspection programs
shall include:

a. In-service design inspections developed in accordance with the damage
tolerance requirements of MIL-A-83444 and the durability requirements of
MIL-A-8866

b. Special inspections to monitor the status of critical areas and support
the milestone schedule requirements of 5.3.2.2

c. Teardown inspection at the completion of the full scale durability test
including any scheduled damage tolerance tests to support the interpretation
and evaluation task of 5.3.8.

5.3.2.4 <u>Test duration</u>. The minimum durability test duration shall be as specified in MIL-A-8867. It may be advantageous to the Air Force to continue testing beyond the minimum requirement to determine life extension capabilities and validate design life capability for usage that is more severe than design usage. The decision to continue testing beyond the minimum duration shall be made based upon a joint review by the contractor and appropriate Air Force activities. The prospective contractors shall provide, in their responses to the request for proposal, the estimated cost and schedule for two additional lifetimes of durability testing beyond the minimum requirement.

5.3.3 <u>Damage tolerance tests</u>. The contractor shall comply with the requirements for damage tolerance tests in MIL-A-8867 as specified in the contract specifications. Prior to initiation of testing, the test plans, procedures, and schedules shall require approval by the Air Force. The damage tolerance test program shall be of sufficient scope to verify Category I fracture critical parts in accordance with MIL-A-83444. The intent shall be to conduct damage tolerance tests on existing test hardware. This may include use of components and assemblies of the design development tests as well as the full scale static and durability test articles. When necessary, additional structural components and assemblies shall be fabricated and tested to verify compliance with the requirements of MIL-A-83444.

5.3.4 <u>Flight and ground operations tests</u>. The contractor shall comply with the detail requirements for flight and ground operations tests in MIL-A-8871 as specified in the contract specifications. Prior to initiation of testing, the test plans, procedures, and schedules shall require approval by the Air Force. An early Full Scale Development (FSD) or Research Development Test and Evaluation (RDT&E) airplane shall be used to perform the flight and ground operations tests. Load measurements shall be made by the strain gage or pressure survey methods agreed to between the contractor and the Air Force. An additional airplane, sufficiently late in the production program to ensure obtaining the final configuration, shall be the backup airplane for these flight tests and shall be instrumented similar to the primary test aircraft. Special types of instrumentation (e.g., recording equipment, mechanical strain recorders, strain gages, etc.) to be used during the loads/environment spectra survey and the individual airplane tracking programs shall be placed on the structural flight test airplane as appropriate for evaluation and correlation. The flight and ground operations tests shall include a flight and ground loads survey and dynamic response tests.

5.3.4.1 <u>Flight and ground loads survey</u>. The flight and ground loads survey program shall consist of operating an instrumented and calibrated airplane within and to the extremes of its limit structural design envelope to measure the resulting loads and, if appropriate, to also measure pertinent temperature profiles on the airplane structure. The objectives of the loads survey shall be as follows:

a. Verification of the structural loads and temperature analysis used in the design of the airframe

b. Evaluation of loading conditions which produce the critical structural load and temperature distribution

c. Determination and definition of suspected new critical loading conditions which may be indicated by the investigations of structural flight conditions within the design limit envelope.

5.3.4.2 Dynamic response tests. The dynamic response tests shall consist of operating an instrumented and calibrated airplane to measure the structural loads and inputs while flying through atmospheric turbulence and during taxi, takeoff, towing, landing, refueling, store ejection, etc. The objectives shall be to obtain flight verification and evaluation of the elastic response characteristics of the structure to these dynamic load inputs for use in sub-stantiating or correcting the loads analysis, fatigue analysis, and for interpreting the operational loads data.

5.3.5 Sonic durability tests. The contractor shall comply with the detail requirements for sonic durability tests in MIL-A-8893 as specified in the contract specifications. Prior to initiation of testing, the test plans, procedures, and schedules shall require approval by the Air Force. Measure-ments shall be made of the acoustic environments on a full scale airplane to verify or modify the initial design acoustic loads/environment. The sonic durability test shall be conducted on a representative airplane (or its major components) to demonstrate structural adequacy for the design service life. Sonic durability tests normally are accomplished by ground testing of the complete airplane with the power plants operating at full power for a time sufficient to assure design service life. However, testing of major portions of the airplane in special nonreverberant ground test stands using the air-plane propulsion system is the noise source, or in high intensity noise facilities, may be acceptable.

5.3.6 Flight vibration tests. The contractor shall comply with the detail requirements for flight vibration tests in MIL-A-8892 as specified in the contract specifications. Prior to initiation of testing, the test plans, procedures, and schedules shall require approval by the Air Force. These tests shall be conducted to verify the accuracy of the vibration analysis. In addition, the test results shall be used to demonstrate that vibration control measures are adequate to prevent cracking and to provide reliable performance of personnel and equipment throughout the design service life.

5.3.7 Flutter tests. The contractor shall comply with the detail require-ments for flutter related tests in MIL-A-8870 as specified in the contract specifications. Prior to initiation of testing, the test plans, procedures, and schedules shall require approval by the Air Force. Flutter related tests shall consist of ground vibration tests, thermoelastic tests, limit load rigidity tests, control surface free play and rigidity tests, and flight flutter tests.

5.3.7.1 <u>Ground vibration tests</u>. The ground vibration tests shall consist of the experimental determination of the natural frequencies, mode shapes, and structural damping of the airframe or its components. The objective is to verify mass, stiffness, and damping characteristics which are used in the aeroelastic analyses (flutter analysis, dynamic analysis, math models, etc.).

5.3.7.2 <u>Structural rigidity tests</u>. The thermoelastic tests, limit load rigidity test, and control surface free play and rigidity tests shall consist of the experimental determination of the structural elastic and free play properties of the airframe and its components. The objective of these tests is to verify supporting data used in aeroelastic analyses and dynamic model design.

5.3.7.3 <u>Flight flutter tests</u>. Flight flutter tests shall be conducted to verify that the airframe is free from aeroelastic instabilities and has satisfactory damping throughout the operational flight envelope.

5.3.8 <u>Interpretation and evaluation of test results</u>. Each structural problem (failure, cracking, yielding, etc.) that occurs during the tests required by this standard shall be analyzed by the contractor to determine the cause, corrective actions, force implications, and estimated costs. The scope and interrelations of the various tasks within the interpretation and evaluation effort are illustrated in figure 4. The results of this evaluation shall define corrective actions required to demonstrate that the strength, rigidity, damage tolerance and durability design requirements are met. The cost, schedule, operational, and other impacts resulting from correction of deficiencies will be used to make major program decisions such as major redesign, program cancellation, awards or penalties, and production airplane buys. Structural modifications or changes derived from the results of the full scale test to meet the specified strength, rigidity, damage tolerance, and durability design requirements shall be substantiated by subsequent tests of components, assemblies, or full scale article as appropriate. (See figure 3.) The test duration for durability modifications shall be as specified in MIL-A-8867 and the contract specifications. The contractor shall propose these additional test requirements together with the associated rationale to the Air Force for approval.

5.4 <u>Force management data package (Task IV)</u>. Maintaining the strength, rigidity, damage tolerance, and durability is dependent on the capability of the appropriate Air Force commands to perform specific inspection, maintenance, and possibly modification or replacement tasks at specific intervals throughout the service life (i.e., at specified depot or base level maintenance times and special inspection periods). To properly perform these tasks, the Air Force must have detailed knowledge of the required actions. Additionally, experience has shown that the actual usage of military airplanes may differ significantly from the assumed design usage. It is necessary that the Air Force have the technical methods and actual usage data to assess the effect of these changes

A-37

in usage on airplane damage tolerance and durability. Task IV describes the minimum required elements of a data package which the contractor shall provide so that the Air Force can accomplish the force management tasks as specified in 5.5. It should be noted that Task IV contains basic ASIP requirements to be performed by the contractor but, unlike Tasks I through III, is not for the purpose of providing compliance to the basic structural design requirements.

5.4.1 Final analyses. The contractor shall revise the design analyses as appropriate to account for significant differences between analysis and test that are revealed during the full scale tests and later during the loads/ environment spectra survey. These analyses updates shall be prepared as discussed below and shall require approval by the Air Force.

5.4.1.1 Initial update of analyses. The design analyses as specified in 5.2 shall be revised when the results of the design development and full scale tests as specified in 5.2.13 through 5.3.7 are available. These initial updates will be used to identify the causes of problems, corrective actions, and production and force modifications required by the interpretation and evaluation of test results task as specified in 5.3.8.

5.4.1.2 Final update of analyses. The initial update of the damage tolerance and durability analyses shall be revised to reflect the baseline operational spectra as specified in 5.4.3. These analysis updates shall form the basis for preparation of the updated force structural maintenance plan as specified in 5.4.3.2. The analyses shall identify the critical areas, damage growth rates, and damage limits required to establish the damage tolerance and durability inspection and modification requirements and economic life estimates required as part of the force structural maintenance plan.

5.4.1.3 Development of inspection and repair criteria. The appropriate analyses (stress, damage tolerance, durability, etc.) shall be used to develop a quantitative approach to inspection and repair criteria. Allowable damage limits and damage growth rates established by the analyses shall be used to develop inspection and repair times for structural components and assemblies. These analyses shall also be used to develop detail repair procedures for use at field or depot level. Special attention shall be placed on defining damage acceptance limits and damage growth rates for components utilizing bonded, honeycomb, or advanced composite types of construction. These inspection and repair criteria shall be incorporated into the force structural maintenance plan as specified in 5.4.3.

5.4.2 Strength summary. The contractor shall summarize the final analyses and other pertinent structures data into a format which will provide rapid visibility of the important structures characteristics, limitations and capabilities in terms of operational parameters. It is desirable that the summary be primarily in diagrammatic form showing the airplane structural limitations and capabilities as a function of the important operational parameters such as

speed, acceleration, center of gravity location, and gross weight. The summary shall include brief descriptions of each major structural assembly, also preferably in diagrammatic form, indicating structural arrangements, materials, critical design conditions, damage tolerance and durability critical areas, and minimum margins of safety. Appropriate references to design drawings, detail analyses, test reports, and other back-up documentation shall be indicated. The strength summary shall require approval by the Air Force.

5.4.3 Force structural maintenance plan. The contractor shall prepare a force structural maintenance plan to identify the inspection and modification requirements and the estimated economic life of the airframe. Complete detailed information (when, where, how, and cost data as appropriate) shall be included. It is intended that the Air Force will use this plan to establish budgetary planning, force structure planning, and maintenance planning. This plan shall require approval by the Air Force.

5.4.3.1 Initial force structural maintenance plan. The initial plan shall be based on the design service life, design usage spectra, the results of the full scale test interpretation and evaluation task as specified in 5.3.7 and the upgraded critical parts list required as specified in 5.1.3.

5.4.3.2 Updated force structural maintenance plan. The force structural maintenance plan shall be updated to include the baseline operational spectra through use of the final analyses update as specified in 5.4.1.2. The first update of the plan shall be based on the analyses that utilized data obtained from the initial phase of the loads/environment spectra survey. Additional updates that may be required to reflect significant changes determined during continuation of the loads/environment spectra survey will be provided through separate negotiation between the Air Force and contractor.

5.4.4 Loads/environment spectra survey. The objective of the loads/environment spectra survey shall be to obtain time history records of those parameters necessary to define the actual stress spectra for the critical areas of the airframe. It is envisioned that 10-20 percent of the operational airplanes will be instrumented to measure such parameters as velocity, accelerations, altitude, fuel usage, temperature, strains, etc. The data will be obtained by the Air Force as part of the force management task as specified in 5.5 and shall be used by the contractor to construct the baseline operational spectrum as specified in 5.4.4.3. Data acquisition shall start with delivery of the first operational airplane. The contractor shall propose, in response to the request for proposal, the number of airplanes to be instrumented and the parameters to be monitored. For the purposes of the program definition, cost estimating, and scheduling, it shall be assumed that the duration of the survey will be 3 years or when the total recorded flight hours of unrestricted operational usage equals one design lifetime, whichever occurs first. The contractor shall also propose the method to be used to detect when a significant change in

speed, acceleration, center of gravity location, and gross weight. The summary shall include brief descriptions of each major structural assembly, also pre- ferably in diagrammatic form, indicating structural arrangements, materials, critical design conditions, damage tolerance and durability critical areas, and minimum margins of safety. Appropriate references to design drawings, detail analyses, test reports, and other back-up documentation shall be indi- cated. The strength summary shall require approval by the Air Force.

5.4.3 Force structural maintenance plan. The contractor shall prepare a force structural maintenance plan to identify the inspection and modification requirements and the estimated economic life of the airframe. Complete detailed information (when, where, how, and cost data as appropriate) shall be included. It is intended that the Air Force will use this plan to establish budgetary planning, force structure planning, and maintenance planning. This plan shall require approval by the Air Force.

5.4.3.1 Initial force structural maintenance plan. The initial plan shall be based on the design service life, design usage spectra, the results of the full scale test interpretation and evaluation task as specified in 5.3.7 and the upgraded critical parts list required as specified in 5.1.3.

5.4.3.2 Updated force structural maintenance plan. The force structural maintenance plan shall be updated to include the baseline operational spectra through use of the final analyses update as specified in 5.4.1.2. The first update of the plan shall be based on the analyses that utilized data obtained from the initial phase of the loads/environment spectra survey. Additional updates that may be required to reflect significant changes determined during continuation of the loads/environment spectra survey will be provided through separate negotiation between the Air Force and contractor.

5.4.4 Loads/environment spectra survey. The objective of the loads/environ- ment spectra survey shall be to obtain time history records of those parameters necessary to define the actual stress spectra for the critical areas of the airframe. It is envisioned that 10-20 percent of the operational airplanes will be instrumented to measure such parameters as velocity, accelerations, altitude, fuel usage, temperature, strains, etc. The data will be obtained by the Air Force as part of the force management task as specified in 5.5 and shall be used by the contractor to construct the baseline operational spectrum as specified in 5.4.4.3. Data acquisition shall start with delivery of the first operational airplane. The contractor shall propose, in response to the request for proposal, the number of airplanes to be instrumented and the para- meters to be monitored. For the purposes of the program definition, cost estimating, and scheduling, it shall be assumed that the duration of the survey will be 3 years or when the total recorded flight hours of unrestricted opera- tional usage equals one design lifetime, whichever occurs first. The contractor shall also propose the method to be used to detect when a significant change in

usage occurs to require an update in the baseline operational spectra. If the individual airplane tracking program as specified in 5.4.5 obtains sufficient data to develop the baseline operational spectra and detect significant usage changes, a separate survey program (or continuation thereof) as described herein may not be required. The scope of the program (e.g., the number of airplanes to be instrumented, and the number and type of parameters to be monitored) will be defined in the contract specifications.

5.4.4.1 Data acquisition provisions. The contractor shall select qualified functioning instrumentation and data recording systems in accordance with the requirements of this standard as specified in the contract specifications. The contractor shall select the specific instrumentation and data recording equipment to accomplish the survey task, obtain Air Force approval of the selections, and make the necessary instrumentation and data recording instal-lations in the specified airplanes. If recording equipment and converter multiplexer equipment are selected, they shall meet the requirements of MIL-R-83165 and MIL-C-83166 respectively. Every effort should be made to use existing qualified instrumentation and recording equipment to reduce program costs and utilize proven operational capabilities. The contract shall specify whether the instrumentation and recording equipment (including spares) shall be Government Furnished Equipment (GFE) or Contractor Furnished Equipment (CFE).

5.4.4.2 Data processing provisions. The contractor shall coordinate with the Air Force the data processing provisions (including reformatting) to be used to ensure that the computer analysis methods will be compatible with the Air Force data analysis system. It is envisioned that contractor facili-ties and personnel, except for reformatting/transcribing and other data pro-cessing and analysis functions for which capabilities exist within the Air Force and are approved for use, will be used to process data collected during the 3-year period beginning with delivery of the first production airplane. Plans for transfer of data processing provisions from contractor to Air Force facilities including training of Air Force personnel shall be included.

5.4.4.3 Analysis of data and development of baseline operational spectra. The contractor shall use the flight data to assess the applicability of the design and durability test loads/environment spectra and to develop baseline operational spectra. The baseline operational spectra shall be used to update the durability and damage tolerance analyses as specified in 5.4.1.2 when a statistically adequate amount of data has been recorded. Subsequent revisions of the baseline operational spectra may be required but will require separate negotiations between the Air Force and contractor.

5.4.5 <u>Individual airplane tracking program</u>. The objective of the individual airplane tracking program shall be to predict the potential flaw growth in critical areas of each airframe that is keyed to damage growth limits of MIL-A-83444, inspection times, and economic repair times. Data acquisition shall start with delivery of the first operational airplane. The program shall include serialization of major components (e.g., wings, horizontal and vertical stabilizers, landing gears, etc.) so that component tracking can be implemented by the Air Force. The contractor shall propose for Air Force review and approval, an individual airplane tracking program for the specific airplane.

5.4.5.1 <u>Tracking analysis method</u>. The contractor shall develop an individual airplane tracking analysis method to establish and adjust inspection and repair intervals for each critical area of the airframe based on the individual airplane usage data. The damage tolerance and durability analyses and associated test data will be used to establish the analysis method. This analysis will provide the capability to predict crack growth rates, time to reach the crack size limits, and the crack length as a function of the total flight time and usage data. The contractor shall coordinate this effort with the Air Force to ensure that the computer analysis method will be compatible with the Air Force data analysis system. The individual airplane tracking analysis method shall require approval by the Air Force.

5.4.5.2 <u>Data acquisition provisions</u>. The contractor shall select qualified functioning instrumentation and data recording systems in accordance with the requirements of this standard as specified in the contract specifications. The recording system shall be as simple as possible and shall be the minimum required to monitor those parameters necessary to support the analysis methods as specified in 5.4.5.1. Counting accelerometers, electrical or mechanical strain recorders, electrical resistance gages, simplified manual data forms, etc. shall be considered. The contractor shall select the specific instrumentation and data recording equipment to accomplish the individual airplane usage tracking, obtain Air Force approval of the selections, and make the necessary instrumentation and data recording installations in the specified airplanes. The contract shall specify whether the instrumentation and recording equipment (including spares) shall be Government Furnished Equipment (GFE) or Contractor Furnished Equipment (CFE).

5.5 <u>Force management (Task V)</u>. Task V describes those actions that must be conducted by the Air Force during force operations to ensure the damage tolerance and durability of each airplane. Task V will be primarily the responsibility of the Air Force and will be performed by the appropriate commands utilizing the data package supplied by the contractor in Task IV with the minimum amount of contractor assistance. Contractor responsibilities in Task V will be specified in the contract specifications.

5.5.1 Loads/environment spectra survey. The Air Force will be responsible for the overall planning and management of the loads/environment spectra survey and will:

a. Establish data collection procedures and transmission channels within the Air Force

b. Train squadron, base, and depot level personnel as necessary to ensure the acquisition of acceptable quality data

c. Maintain and repair the instrumentation and recording equipment

d. Ensure that the data are of acceptable quality and are obtained in a timely manner so that the contractor can analyze the results, develop the baseline spectrum (see 5.4.4.3), and update the analyses (see 5.4.1.2) and force structural maintenance plan (see 5.4.3.2).

The Air Force will also be responsible for ensuring that survey data are obtained for each type of usage that occurs within the force (training, recon-naissance, special tactics, etc.). Subsequent to completion of the initial data gathering effort, the Air Force will elect whether or ¬ot to continue to operate either all or a portion of the instrumentation and recording equip-ment aboard the survey airplanes to support additional updates of the baseline spectra and force structural maintenance plan.

5.5.2 Individual airplane tracking data. The Air Force will be responsible for the overall planning and management of the individual airplane tracking data gathering effort and will:

a. Establish data collection procedures and data transmission channels within the Air Force

b. Train squadron, base, and depot level personnel as necessary to ensure the acquisition of acceptable quality data

c. Maintain and repair the instrumentation and recording equipment

d. Ensure that the data are obtained and processed in a timely manner to provide adjusted maintenance times for each critical area of each airplane.

5.5.3 Individual airplane maintenance times. The Air Force will be responsible for deriving individual maintenance (inspection and repair) times for each critical area of each airplane by use of the tracking analysis methods as specified in 5.4.5.1 and the individual airplane tracking data as specified in 5.5.2. The objective is to determine adjusted times at which the force

structural maintenance actions as specified in 5.4.3 have to be performed on
individual airplanes and each critical area thereof. With the force structural
maintenance plan and the individual aircraft maintenance time requirements
available, the Air Force can schedule force structural maintenance actions
on a selective basis that accounts for the effect of usage variations on
structural maintenance intervals.

5.5.4 Structural maintenance records. AFLC and the using command will be
responsible for maintaining structural maintenance records (inspection, repair,
modification, and replacement) for individual airplanes. These records shall
contain complete listings of structural maintenance actions that are performed
with all pertinent data included (Time Compliance Technical Order (TCTO) action,
component flight time, component and airplane serial number, etc.).

6. NOTES

6.1 Data requirements. The data requirements in support of this standard
will be selected from the DOD Authorized Data List (TD-3) and will be reflected
in a contractor data requirements list (DD Form 1423) attached to the request
for proposal, invitation for bids, or the contract as appropriate.

6.2 Relationship to system engineering management. When appropriate, the
conduct of the work efforts by the contractor in achieving airplane structural
integrity will be included in the System Engineering Management Plan in accord-
ance with MIL-STD-499A(USAF) for the airplane and will be compatible with the
system safety plan in accordance with MIL-STD-882.

Custodian:
  Air Force - 11

Review activities:
  Air Force - 01, 10, 16

Preparing activity:
  Air Force - 11

Project No. 1SGP-F019

TABLE I. USAF Aircraft structural integrity program tasks.

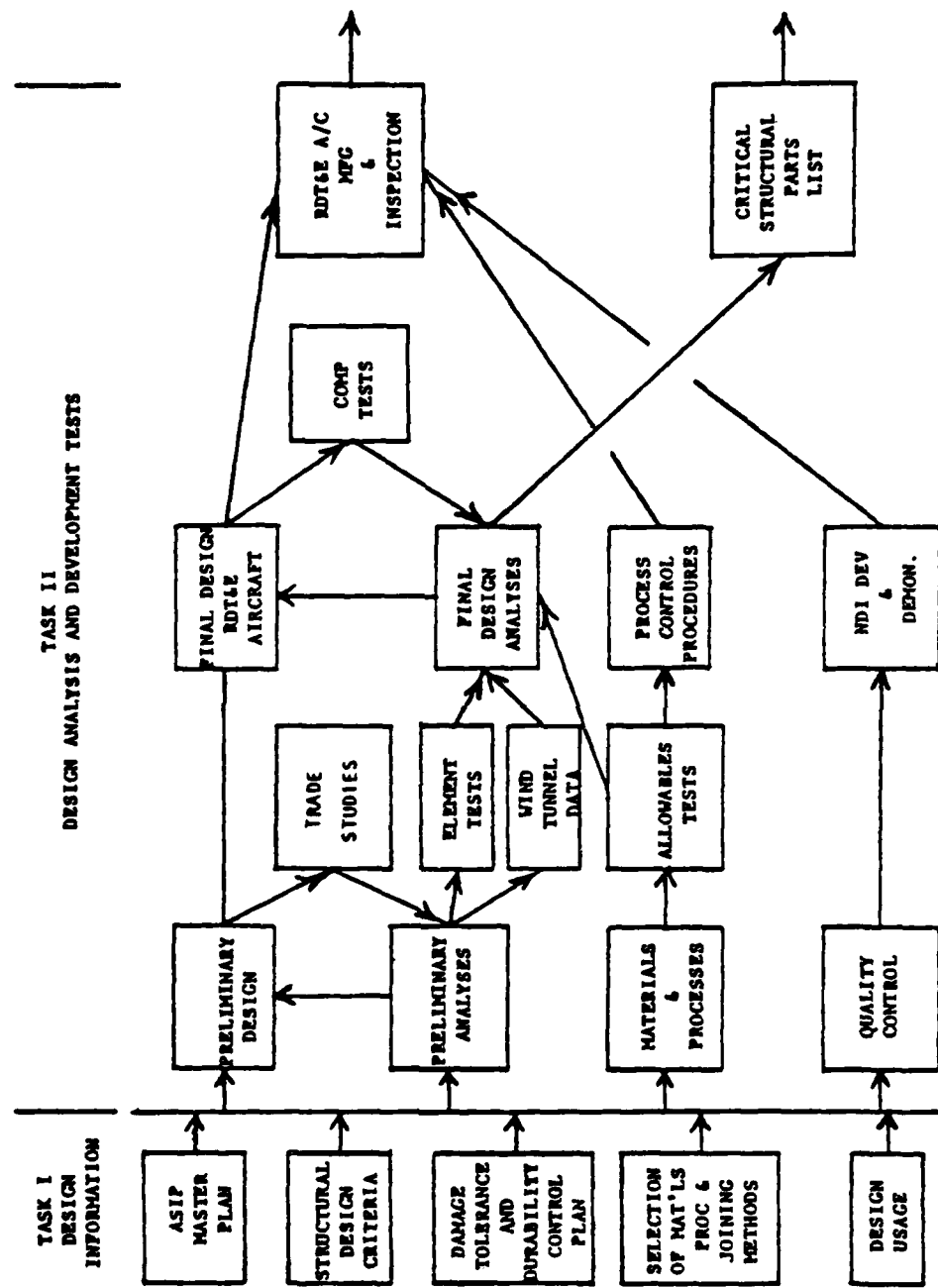| TASK I	TASK II	TASK III	TASK IV	TASK V
DESIGN INFORMATION	DESIGN ANALYSES AND DEVELOPMENT TESTS	FULL SCALE TESTING	FORCE MANAGEMENT DATA PACKAGE	FORCE MANAGEMENT
ASIP MASTER PLAN	MATERIALS AND JOINT ALLOWABLES	STATIC TESTS	FINAL ANALYSES	LOADS/ENVIRONMENT SPECTRA SURVEY
STRUCTURAL DESIGN CRITERIA	LOAD ANALYSIS	DURABILITY TESTS	STRENGTH SUMMARY	INDIVIDUAL AIRPLANE TRACKING DATA
DAMAGE TOLERANCE & DURABILITY CONTROL PLANS	DESIGN SERVICE LOADS SPECTRA	DAMAGE TOLERANCE TESTS	FORCE STRUCTURAL MAINTENANCE PLAN	INDIVIDUAL AIRPLANE MAINTENANCE TIMES
SELECTION OF MAT'LS, PROCESSES, & JOINING METHODS	DESIGN CHEMICAL/THERMAL ENVIRONMENT SPECTRA	FLIGHT & GROUND OPERATIONS TESTS	LOADS/ENVIRONMENT SPECTRA SURVEY	STRUCTURAL MAINTENANCE RECORDS
DESIGN SERVICE LIFE AND DESIGN USAGE	STRESS ANALYSIS	SONIC TESTS	INDIVIDUAL AIRPLANE TRACKING PROGRAM	
	DAMAGE TOLERANCE ANALYSIS	FLIGHT VIBRATION TESTS		
	DURABILITY ANALYSIS	FLUTTER TESTS		
	SONIC ANALYSIS	INTERPRETATION & EVALUATION OF TEST RESULTS		
	VIBRATION ANALYSIS			
	FLUTTER ANALYSIS			
	NUCLEAR WEAPONS EFFECTS ANALYSIS			
	NON-NUCLEAR WEAPONS EFFECTS ANALYSIS			
	DESIGN DEVELOPMENT TESTS			

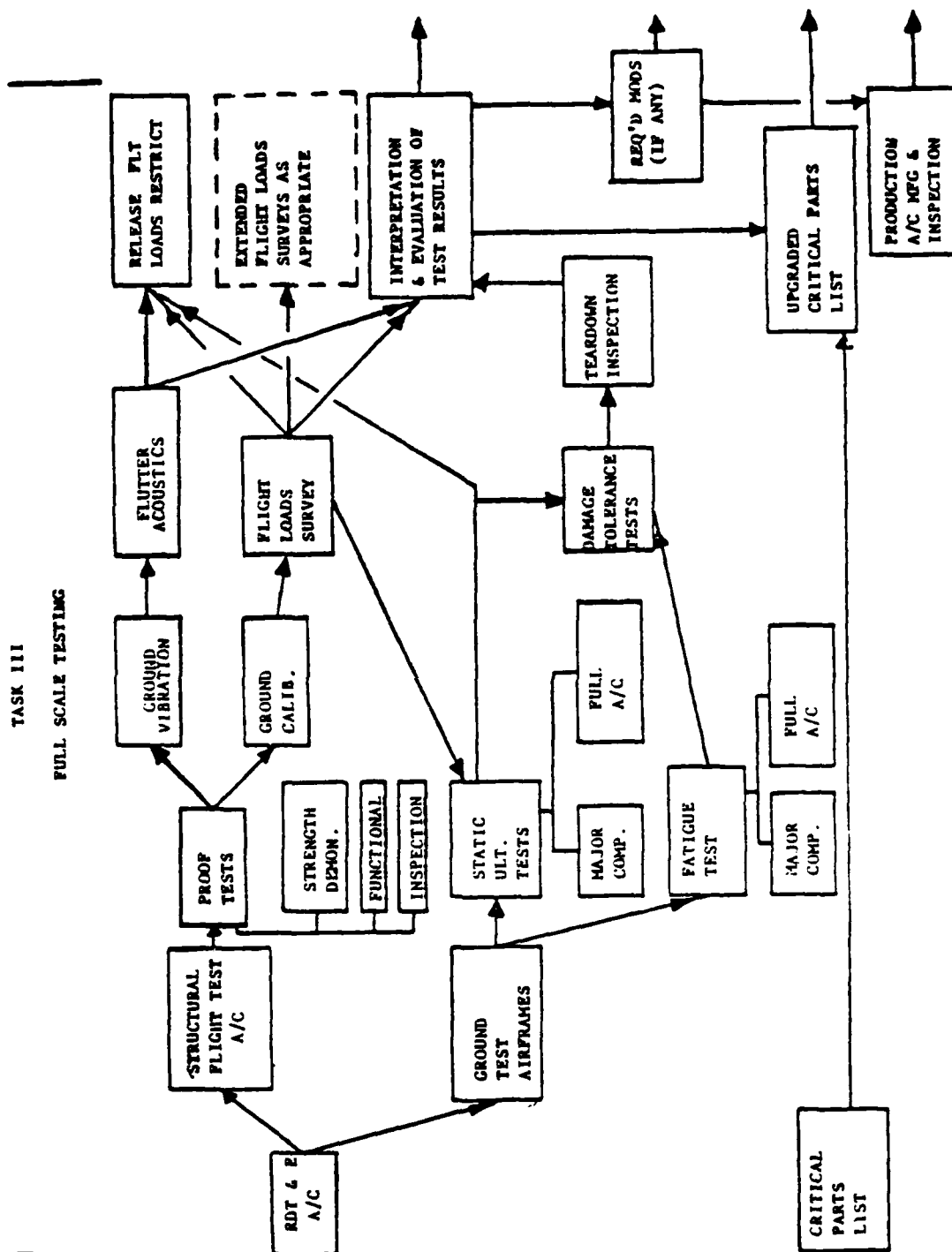FIGURE 1. Aircraft structural integrity program.

A-45

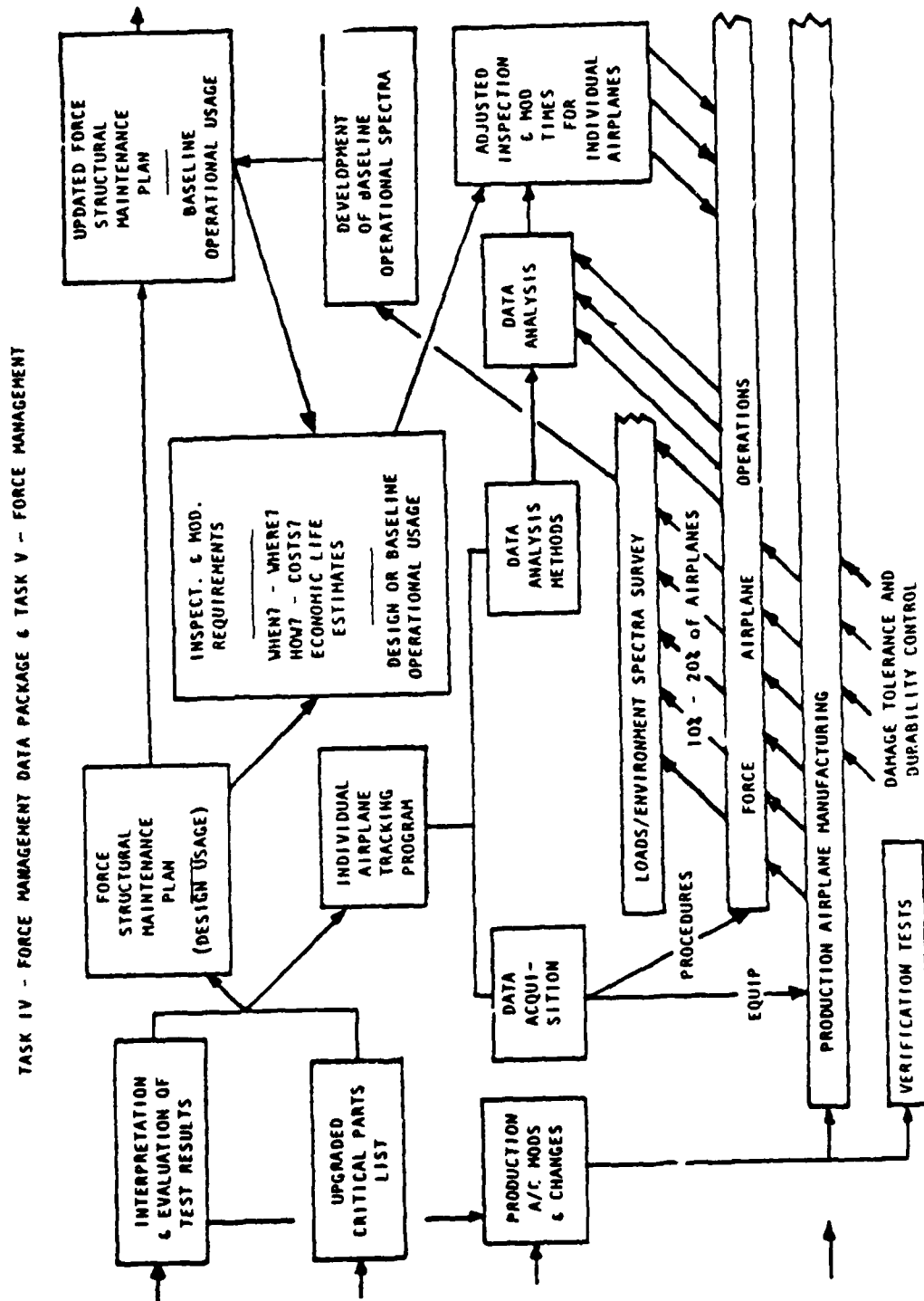FIGURE 2. Aircraft structural integrity program.
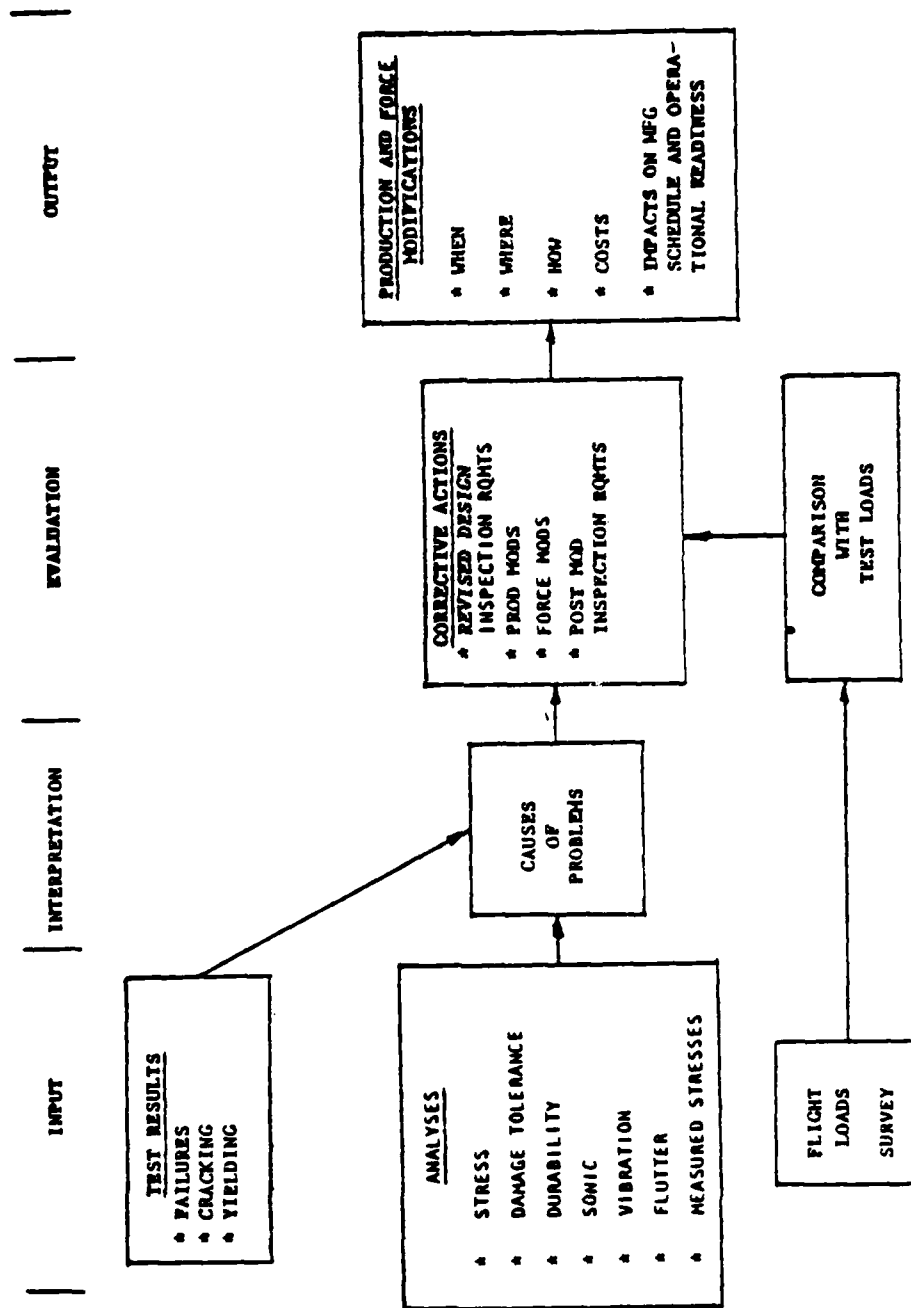
FIGURE 3. Aircraft structural integrity program.

FIGURE 4. Interpretation and evaluation of test results (based on design service life and design usage).

STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

OMB Approval
No. 22-R255

INSTRUCTIONS: The purpose of this form is to solicit beneficial comments which will help achieve procurement of suitable products at reasonable cost and minimum delay, or will otherwise enhance use of the document. DoD contractors, government activities, or manufacturers/vendors who are prospective suppliers of the product are invited to submit comments to the government. Fold on lines on reverse side, staple in corner, and send to preparing activity. Comments submitted on this form do not constitute or imply authorization to waive any portion of the referenced document(s) or to amend contractual requirements. Attach any pertinent data which may be of use in improving this document. If there are additional papers, attach to form and place both in an envelope addressed to preparing activity.

DOCUMENT IDENTIFIER AND TITLE

NAME OF ORGANIZATION AND ADDRESS	CONTRACT NUMBER
	MATERIAL PROCURED UNDER A
	☐ DIRECT GOVERNMENT CONTRACT ☐ SUBCONTRACT

1. HAS ANY PART OF THE DOCUMENT CREATED PROBLEMS OR REQUIRED INTERPRETATION IN PROCUREMENT USE?

   A. GIVE PARAGRAPH NUMBER AND WORDING.

   B. RECOMMENDATIONS FOR CORRECTING THE DEFICIENCIES

2. COMMENTS ON ANY DOCUMENT REQUIREMENT CONSIDERED TOO RIGID

3. IS THE DOCUMENT RESTRICTIVE?

   ☐ YES   ☐ NO *(If "Yes", in what way?)*

4. REMARKS

SUBMITTED BY *(Printed or typed name and address - Optional)*	TELEPHONE NO.
	DATE

DD FORM JAN 72 **1426**   REPLACES EDITION OF 1 JAN 66 WHICH MAY BE USED

C16061

A-49

ASD/ENYESS
Wright-Patterson AFB, O 45433

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300

POSTAGE AND FEES PAID
DEPARTMENT OF THE AIR FORCE
DoD-318

ASD/ENYESS
Wright-Patterson AFB, Ohio 45433

FOLD

A-50

APPENDIX B

BREAKDOWN OF FORCE MANAGEMENT ELEMENTS

Major Element - Final Analyses

Sub-Element - Initial Update of Design Analyses

Work Task - The design analyses are revised using the results from the design development and full scale tests. The objective is to identify the causes of problems determined from tests, determine the corrective actions needed, and provide the production and/or force modifications required. In addition, these revised analyses are used to develop inspection and repair criteria.

Work Responsibility - Airframe Contractor

Management Responsibility - AFSC/ASD

Input Required

       (1)   Design Analyses

       (2)   Design Development Tests

       (3)   Full Scale Tests

Output Required

       (1)   Production and/or force modifications required

       (2)   Inspection and repair criteria

       (3)   Updated design analyses

Major Element - Final Analyses

Sub-Element - Final Update of Analyses

Work Task - The initial update of the design analyses concerning the damage tolerance and durability analyses are revised to reflect the baseline operational spectra determined during the L/ESS program. These revised analyses will identify the critical areas, damage growth rates, and damage limits required to establish the damage tolerance and durability inspection and modification requirements and economic life estimates.

Work Responsibility - Airframe Contractor

Management Responsibility - AFSC/ASD

Input Required -

      (1)   Updated design analyses

      (2)   Baseline operational spectra

Output Required -

      (1)   Final update of the damage tolerance and durability analyses.

<u>Major Element</u> - Strength Summary

<u>Sub-Element</u> - none

<u>Work Task</u> - The important structural characteristics, limitations, and operational capabilities are summarized. This summary includes discussions of:

      (1)   structural limitations

      (2)   structural capabilities

      (3)   major structural assembly descriptions

      (4)   structural arrangements

      (5)   materials

      (6)   critical design conditions

      (7)   damage tolerance and durability critical areas

      (8)   minimum margins of safety

<u>Work Responsibility</u> - Airframe contractor

<u>Management Responsibility</u> - AFSC/ASD

<u>Input Required</u> -

      (1)   Updated design analyses

<u>Output Required</u>

      (a)   Strength summary report

Major Element - Force Structural Maintenance Plan

Sub-Element - Initial Force Structural Maintenance Plan

Work Task - Develop a plan to identify the inspection and modification requirements of the airframe as well as the costs. For each inspection and modification, the details to the when, where, how, and cost are provided.

Work Responsibility - Airframe Contractor

Management Responsibility - AFFC/ASD

Input Required -

      (1)   Inspection and repair criteria

      (2)   Updated design analyses

      (3)   Design Information

Output Required

      (1)   Initial Force Structural Maintenance Plan Report

Major Element - Force Structural Maintenance Plan

Sub-Element - Updated Force Structural Maintenance Plan

Work Task - The initial force structural maintenance plan is revised to reflect the results of the final update of analyses. This task is based on the operational usage obtained from the L/ESS program.

Work Responsibility - Airframe Contractor

Management Responsibility - AFLC/ALC

Input Required -

(1) Final update of the damage tolerance and durability Analyses

(2) Initial Force Structural Maintenance Plan

Output Required -

(1) Updated Force Structural Maintenance Plan

Major Element - Loads/Environment Spectra Survey (L/ESS)

Sub-Element - L/ESS Contractor's Task (Task IV)

Work Task -

(1) Propose the number of aircraft to be instrumented

(2) Select the parameters to be monitored

(3) Select the instrumentation and data recording systems

(4) Install instrumentation and data recording systems

(5) Develop computer analysis methods compatible with ASIMIS (AFLC)

(6) Process data into required form

(7) Develop the baseline operational spectra

(8) Develop the method used to detect when a change in usage requires an update in the baseline operational spectra

Work Responsibility - Airframe Contractor

Management Responsibility - AFSC/ASD or AFLC/ALC according to who has program management responsibility. AFLC/ASIMIS concerning data reformatting and transcribing.

Input Required -

(1) Design Analyses

(2) Full Scale Tests

(3) Reformatted/transcribed flight recorded data from ASIMIS

Output Required -

(1) An installed and working recording system

(2) A data processing system

(3) Baseline operational spectra

(4) Method to detect change in usage

<u>Major Element</u> - Individual Airplane Tracking (IAT)

<u>Sub-Element</u> - IAT Contractor's Task (Task IV)

<u>Work Task</u> -

    (1)   Develop a method to predict crack growth rates, time to reach crack size limits, and the crack length as a function of flight time and usage data for each individual airplane.

    (2)   Select the instrumentation and data recording systems

    (3)   Install instrumentation and data recording systems

<u>Work Responsibility</u> - Airframe Contractor

<u>Management Responsibility</u> - AFSC/ASD or AFLC/ALC according to who has program management responsibility

<u>Input Required</u> -

    (1)   Initial update of design analyses

<u>Output Required</u> -

    (1)   Individual airplane tracking analysis method report.

    (2)   An installed and working data collection system.

Major Element - Loads/Environment Spectra Survey (L/ESS)

Sub-Element - L/ESS Air Force Task (Task V)

Work Task -

    (1) Establish data collection procedures and transmission channels

    (2) Train personnel as necessary to ensure acceptable quality data.

    (3) Operate, maintain, and repair the instrumentation and recording system.

    (4) Collect, prepare, and send data to ASIMIS

    (5) Process, evaluate, and transfer data to airframe contractor and ALC.

    (6) Ensure acceptable quality and timely data.

    (7) Determine when to discontinue program.

    (8) Determine if additional programs are needed.

Work Responsibility -

AFSC/ASD (1) (2) (6) (7) above, AFLC/ALC (1) (2) (6) (7) (8) above

AFLC/ASIMIS - (5) above

Operating Command - (2) (3) (4) above

Management Responsibility -

AFSC/ASD or AFLC/ALC according to who has program management

responsibility.

Input Required -

    (1) Method to detect change in usage

Output Required -

    (1) Reformatted/transcribed flight recorder data (ASIMIS)

    (2) Decision to stop/start-up program (AFLC/ALC)

Major Element - Individual Airplane Tracking (IAT)

Sub-Element - IAT Air Force Task (Task V)

Work Task -

(1) Establish data collection procedures and transmission channels.

(2) Train personnel as necessary to ensure acceptable quality data.

(3) Operate, maintain, and repair the instrumentation and data recording system.

(4) Collect, prepare, and send data to appropriate AFLC organization.

(5) Process, evaluate, and present data to appropriate AFLC organization.

Work Responsibility -

AFSC/ASD - (1) (2) above

AFLC/ALC - (1) (2) above

AFLC/ASIMIS - (5) above

Operating Command - (2) (3) (4) above

Management Responsibility -

AFSC/ASD or AFLC/ALC according to who has program management responsibility

Input Required -

(1) Individual airplane tracking analysis method

Output Required -

(1) Data for individual airplanes defining the potential flaw growth in critical areas of each airframe.

(2) For some systems, inspections times for individual airplanes.

Major Element - Individual Airplane Maintenance Times

Sub-Element - none

Work Task -

    (1)   Determine the times at which the force structural maintenance actions defined in the force structural maintenance plan have to be performed on individual airplanes and each critical area.

    (2)   Schedule required structural maintenance actions.

    (3)   Release required directives to implement structural maintenance actions.

Work Responsibility - AFLC/ALC

Management Responsibility - AFLC/ALC

Input Required -

    (1)   Force Structural Maintenance Plan

    (2)   Data for individual airplanes defining the potential flaw growth and time to inspection for some aircraft systems.

Output Required

    (1)   Directives (T.O.'s, TCTO's, etc.) defining the structural maintenance actions to be performed on individual airplanes.

Major Element - Structural Maintenance Records

Sub-Element - none

Work Task - Record and maintain the history of all structural maintenance actions (inspection, repair, modification, and replacement) performed on each individual airplane.

Work Responsibility - Operating command and AFLC/ALC

Management Responsibility - AFLC/ALC

Input Required -

(1) Directives defining the structural maintenance actions to be performed

Output Required - Structural maintenance records

APPENDIX C

DATA PROCESSING METHODS

Processing of Air Force ASIP data is the responsibility of the ASIMIS office at Tinker Air Force Base, Oklahoma. The ASIP data processing system for each aircraft system is procured from a contractor by the ASD or ALC System Manager for eventual operation at ASIMIS. Most current operational systems have suffered early problems because ASIMIS was not provided the opportunity to review the processing system requirements prior to procurement. ASIMIS review will ensure that the processing system is compatible with ASIMIS computer equipment and that the software contains those features which have proved successful during previous operation on other aircraft systems.

During the design and implementation of the processing system at ASIMIS, the contractor is required to demonstrate proper functioning of the systems by processing a sample of actual data. To adequately test all of the editing checks, it is necessary for the contractor to process a large sample of data, and to implement required improvements to the system logic, before the formal delivery of the software to ASIMIS. Since the initial recording system installations are quite often delayed for one reason or another, and the software is a scheduled delivery, there is a tendency to force software delivery without adequate testing. This generally results in the delivery of inefficient systems with deficient editing capability which requires rework by the contractor or by ASIMIS and causes additional delays in starting the processing of the ASIP data. It is generally desirable for the contractor to process data for one or two years before the system is transitioned to ASIMIS and then to provide consultation to ASIMIS for one or two years after transition. This allows the contractor time to measure and improve system efficiency and provides training for ASIMIS on the new system.

The requirements of an ASIP data processing system are as follows:

(a) Feedback to maintain/improve data quality

(b) Protect file from erroneous entries

(c) Provide input for routine structural maintenance analysis

(d) Maintain file for analysis of future structural problems

(e) Provide historical structural utilization data

(f) Provide historical loads for structural design criteria

The two ASIP data collection programs, the individual aircraft tracking program and the loads/environmental spectra survey program, individually and collectively are designed to meet these requirements. The data processing systems can be divided into the following steps: data transcription, editing and feedback, and reduction and analysis. The following paragraphs discuss these steps in detail.

C.1 DATA TRANSCRIPTION

Data transcription is that step which converts the raw input data from the field format to a computer compatible form. This step is performed by Air Force personnel at ASIMIS, at an ALC, or at an operational base depending on the particular system. Figure C-1 illustrates the various data transcription methods in current use.

All of the current L/ESS tape recorders use special tape cassettes with high packing densities and special formats to increase tape capacity. Each type of cassette requires a special playback unit called a reformatter/transcriber (R/T) which reads the cassette tape, reformats the data in standard computer tape format, writes the data on a computer tape, and erases and records the cassette tape for reuse. The R/T units for the MXU-553A cassettes, the AN/ASH-28 (F-15) cassettes, and the A/A24U-10 (F-4) cassettes are located at Tinker Air Force Base, ASIMIS. The R/T units for the MADAR (C-5) cassettes and the A/A34U-6 (F-111) cassettes are located at operational bases to minimize shipping of cassettes and computer compatible tapes are sent to ASIMIS.
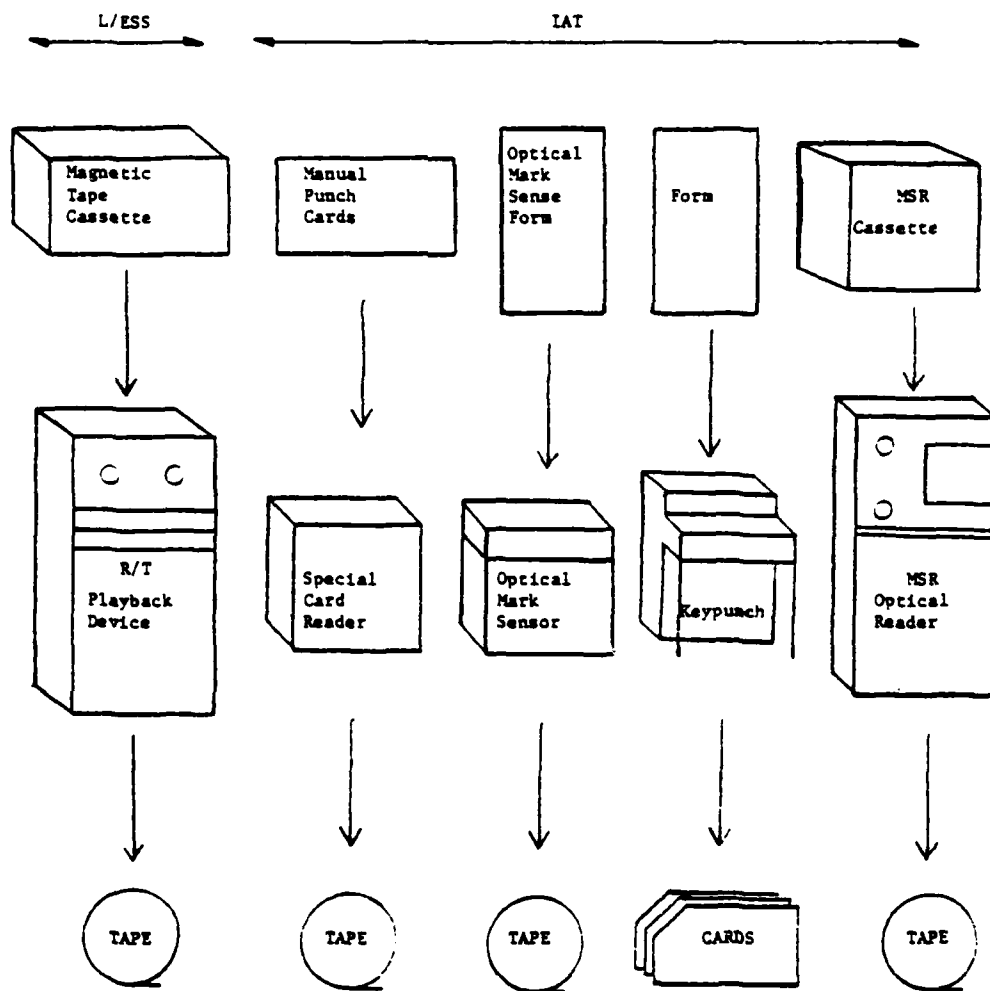
Figure C-1. Data Transcription Methods.

The means by which the individual tape cartridges are obtained by ASIMIS is provided by the Air Force part supply logistics system. When the cartridges are removed from the aircraft, they are exchanged for blank cartridges to be reinstalled in the recorders. The recorded tape cartridges are classified as "repairable parts" and are sent to ASIMIS at Tinker AFB for "repair". At ASIMIS the tapes are processed, erased, and put back into the supply system as "repaired parts".

This method of tape cartridge supply has its shortcomings, however. The most common complaint is that the recorded tapes are not put into the supply system immediately after removal with delays of several days or even weeks. The recorded cartridges apparently lie on a desk until a new supply of blank cartridges are needed, and then the recorded cartridges are turned in. The most serious consequence of this delay is that problems with the recording system are not detected until the data is processed at ASIMIS, and so a delay in processing the data results in a delay in detecting and repairing malfunctioning data channels.

Another problem which ASIMIS has had is properly identifying the data tapes as they come in for processing. Some of the aircraft have provisions for enough data available in the header information for complete identification; some do not. However, even when provisions for enough identification have been made, sometimes the data are erroneous or omitted. In order to provide a supplementary source of tape cartridge information, the AFTO 495 Form has been installed in the ASIP system. The AFTO 495 form will aid in identifying some data which would otherwise have been discarded.

Since the tape cartridge generated by the MXU-553/A Airborne Digital recorder is not compatible with standard digital computer systems, it must be reformatted and transcribed before processing. The Reformatter/Transcriber (R/T) consists of a mini-computer equipped with a tape deck to read the tape cartridge from the recorder, a teletype unit, and an output tape drive which writes a tape compatible with most computer systems. The teletype is used to initiate the R/T-stored processing program and to input various information to be included at the beginning of each tape processed.

Basically, the function of the R/T is to play back the essentially gapless 1/2 inch, 9-track tape cartridge (actually, there is a one-byte gap every 2 seconds) tape from the MXU-553/A recorder and write a standard computer-compatible 1/2-inch tape containing interrecord gaps (3/4 inch) and an end-of-file mark recognizable to standard digital computer tape drives. The R/T is capable of writing either a standard 7-track or a standard 9-track tape (800 bpi).

At the completion of processing by the R/T, a history of the transcription is printed on the teletype. This history includes a variety of information, most of which is self-explanatory. The input block count is a count of the number of input tape records. The output block count is the number of physical records (the data contained between consecutive 3/4-inch interrecord gaps) on the reformatted tape. The input error count is the number of input tape records read which contain parity errors. These parity errors are the results of either a bad write by the recorder or a bad read by the reformatter. The output error count is the number of output physical records containing parity errors that were written by the R/T. It should be noted that these are detected by the R/T, since it immediately reads what it has written, but they are left uncorrected since the R/T cannot stop processing the input tape for the time required to backspace and rewrite the faulty record on the output tape.

Similar data transcription procedures are used for the AN/ASH-28, A/A24U-6, and MADAR recorder cassettes.

To transcribe IAT data from special forms, Warner-Robins ALC has acquired optical mark sensor equipment with checking and editing capability. This equipment automatically senses marks entered at specific locations on preprinted forms, assigns a specific parameter identification and value to each word, and writes the data on a computer tape. The device can check for missing or conflicting entries and provides a list of errors. Corrections can be made by preparing a corrected form with minimum identification and only the corrected entries which replaces the incorrect

entries on the computer tape. This device saves the cost of keypunching and associated keypunch errors.

All other forms utilized in IAT or L/ESS programs are transcribed to computer card form by a keypunch. The keypunching is performed by the contractor during the initial stages of the program and then the keypunching duties are assumed by the ALC where the System Manager is located except in the case of the F-4 where ASIMIS does the keypunching of the monthly counting accelerometer forms.

One other method of IAT data transcription is being used for the MSR (mechanical strain recorder) data on the F-16 ASIP. An automatic reader is at ASIMIS which will magnify the recorded scratch on the MSR tape, advance the tape through the unit, optically measure the time history of the scratch deflection, detect and record the amplitudes of each peak and trough deflection and write the recorded values on a computer tape.

The data must be transmitted in its raw form from the collection site to the organization which performs the data transcription. In the case of inexpensive one-time data collection media, such as forms, this transmittal represents no problem. However, in the case of expensive reusable media such as A/A34U-10, MSR, and other cassettes, a considerable amount of resources are tied up in this supply pipeline. This is further complicated because shipping damage can be a major cause of cassette failure. These considerations have led the C-5 and F-111 systems to go to R/T units located at the bases and the F-4 system to use a portable intermediate tape copier which copies the cassette tape image onto an inexpensive small tape which is mailed back to ASIMIS for input to the R/T.

C.2   EDITING AND FEEDBACK

The primary objectives of this step of the ASIP data processing are to protect the data file from errors and to provide feedback to the field to improve data quality.

For the L/ESS program, the elimination of data errors is a complex task because most, if not all, input data tapes have errors or anomalies, which, if allowed to pass into the processing and analysis, would comtaminate the data files or cause abnormal software run termination. Recorder write errors, as evidenced by tape parity errors, are eliminated and counted by the R/T unit. If the parity error count is a large percentage of the total tape records, the remaining data may not adequately represent the usage and the entire tape is eliminated. Occasional intermittent errors, such as spikes to zero on full-scale, are replaced by assuming a linear change in value during the replaced period of time. For each aircraft system, some of the L/ESS parameters are not considered critical for the analysis and, if errors are encountered in the data for these parameters, the data is processed without the erroneous non-critical parameters.

Extensive errors in a critical parameter cause the entire flight or data tape to be excluded from further processing. Any data error which appears to be the result of malfunctioning recording equipment or improper data collection procedures is reported to the field via the system manager so that corrective action can be taken.

For the MXU-553A data, ASIMIS has a standardized RECAP (Recorder Analysis Program) program which performs fault isolation and prints a fault summary for each cassette on microfiche for use by the ASIP OPR in maintaining the recorder equipment. ASIMIS processes each cassette through the RECAP and sends the output to the ASIP OPR within 48 hours after receipt of the cassette. The ASIP OPR reviews the RECAP output and determines whether any corrective action is needed. Factors which affect his determination include: 1) Is the malfunctioning channel actually critical for the data analysis?; 2) Is replacement hardware available?; 3) Is the planned corrective action likely to be effective?; and 4) Is there an impending structural problem which places a priority on the ASIP data collection effort?

Most ASIP systems also have a separate editing program which has specialized parameter checks and which may perform some preliminary data reduction. For example, it could include the derivation of angular acceleration time histories from the recorded angular rates and the compression of the recorded data to eliminate up to 95 percent of the recorded parameter values found to be uninteresting from a structural analysis standpoint. The output of this program may allow subsequent manual intervention such as the deletion of an erroneous data channel or an entire flight with useless data so the remainder of the tape may be processed.

The objective of data time history compression is to compress the data to a fraction of its original volume with no significant qualitative loss. This is desirable primarily to facilitate storing of data tapes for future processing, particularly of time history data. Reducing the volume of tapes to be stored is then the primary objective of this effort. A secondary benefit results from the fact that once the data has been unpacked, checked, compressed and reordered, it is then in a form that can be processed through the data program more efficiently.

C.3 DATA REDUCTION AND ANALYSIS

The data reduction and analysis includes those data processing operations which start with the edited, recorded data and proceed through the calculation of load cycles, the calculation of stress cycles at structural control points, and the calculation of the rate of life expenditure for critical structural components. This analysis is directed toward the development of the data base for fleet life and maintenance requirement projections and individual aircraft life and maintenance requirement projections from recorded usage tracking data.

C.3.1 L/ESS Systems

Because of the variations from system to system in those usage factors and structural design details which affect life and because the L/ESS software is purchased as part of the total aircraft system procurement, there is little or no commonality in

data reduction and analysis methods. Some systems completely separate the data reduction from the analysis function while other systems combine them into a single set of software. Some systems have the data reduction and analysis performed by ASIMIS, some systems have both tasks performed by the airframe contractor, and many systems divide the two tasks with ASIMIS doing the data reduction and the contractor doing the analysis.

Data reduction is normally performed by selecting from the recorded data specific time slices which are known to contain a peak or trough of a load because one of the key recorded parameters had a peak or trough at that time. Then the value of load is calculated at the selected time slices. An alternate approach consists of calculating a time history of load values during all periods of activity and then selecting the load peaks and troughs from the time history. This alternate approach is used where no key recorded parameter is considered to be an adequate indicator of the load peaks and troughs. The alternate approach has a much higher computational cost.

The load peak and trough occurrences are identified by mission and flight condition parameters so that the load environment can be projected from the anticipated mission data. During a later parametric analysis, the load spectrum is formed for each combination of mission and flight condition parameter values as a function of total time spent in that condition or the number of occurrences of that condition (for landings, pressurizations, etc).

Data reduction includes other operations such as the conversion of the recorded digital data to decimal values of engineering units. Depending on the location of the accelerometers in the aircraft and the magnitude of the angular motion, it may be necessary to correct the recorded accelerations to the aircraft center-of-gravity using rigid body equations of motion.

An alternate use of the L/ESS data is to define aircraft usage by mission type for incorporation into design criteria. The software should be designed to provide an output data tape, following all data editing operations, which can be used as input

to a design criteria processing system. ASIMIS, with support from the Aeronautical Systems Division, should provide a standardized output product for use in developing design criteria. This product should be a tape of recorded data, compressed to eliminate inactive data and edited to eliminate data errors and flights with invalid data.

C.3.2 IAT Systems

The IAT data reduction consists primarily of the formation of a data base including usage information and projected life and inspection schedules for individual aircraft and their tracked components. These data bases are designed for access by authorized individuals via telecommunications network.

During the data reduction, recorded usage data is transformed into an estimate of minimum time to critical crack length. There are several variations of this transformation process. In the case of forms data, the time spent in various flight profile categories is converted to a corresponding load or stress history by a parametric analysis. When a load factor or a strain time history is recorded, it is generally necessary to transfer the recorded data to stresses at a critical structural location. The time to critical crack length is computed using the stress history and the initial crack length which is assumed for a new part and then updated for each period of use. The crack length may be reset following an inspection or a repair action.

The analysis portion of the IAT system determines, from the projected crack growth, what inspection or maintenance actions should be scheduled for each individual aircraft.